

Baseline Design of an eRHIC Detector and Interaction Region

A. Kiselev for the BNL EIC taskforce

DIS 2014 Warsaw

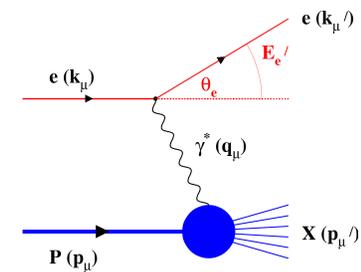


Physics requirements

WHAT IS NEEDED TO REALIZE EIC PROGRAM

Inclusive Reactions in ep/eA:

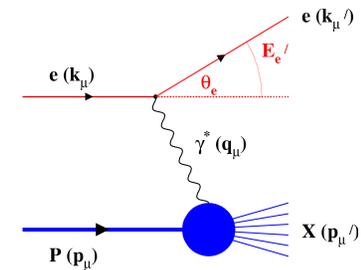
- Physics: Structure Fcts.: g_1 , F_2 , F_L
- Very good electron id \rightarrow identify scattered lepton
- Momentum/energy and angular resolution of e' critical
- scattered lepton \rightarrow kinematics of event (x, Q^2)



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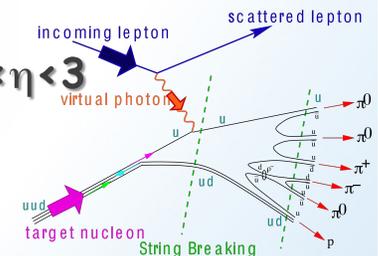
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Semi-inclusive Reactions in ep/eA:

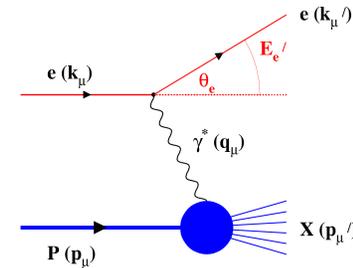
- ❑ Physics: TMDs, Helicity PDFs, FF \rightarrow flavor separation, dihadron-corr., ...
 \rightarrow **Kaon asymmetries, cross sections**
- ❑ Excellent particle ID: π^\pm, K^\pm, p^\pm separation over a wide range in $-3 < \eta < 3$
 \rightarrow excellent momentum resolution at forward rapidities
- ❑ TMDs: full Φ -coverage around γ^* , wide p_T coverage
- ❑ Excellent vertex resolution \rightarrow Charm, Bottom separation



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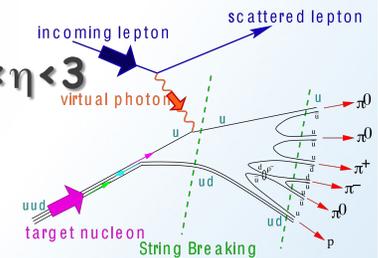
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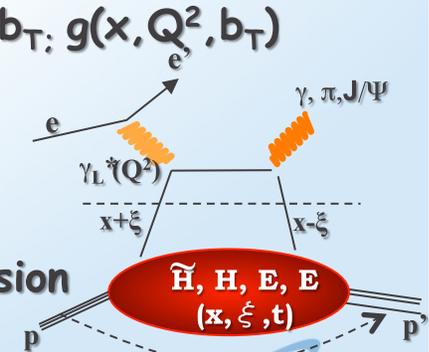
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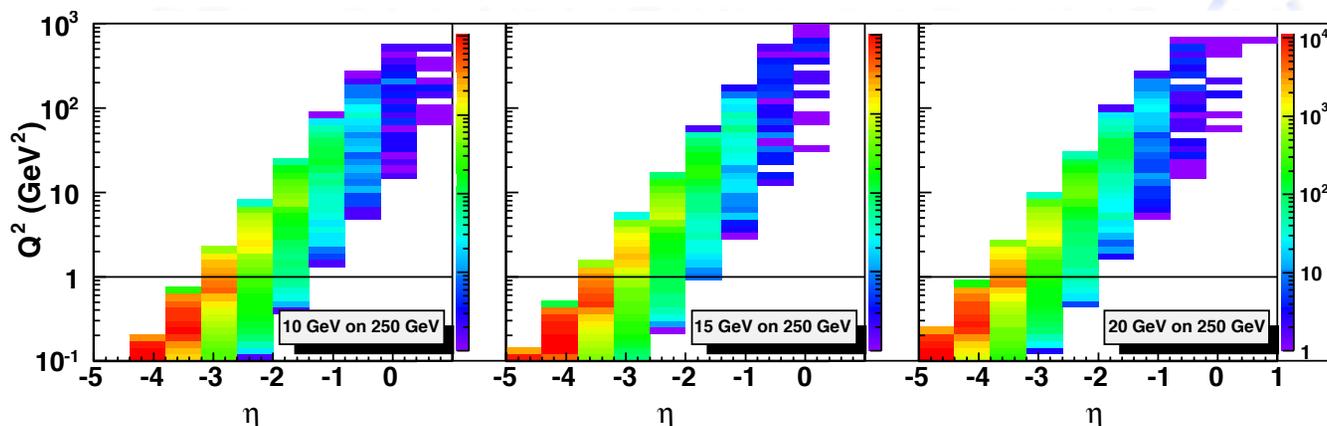


Exclusive Reactions in ep/eA:

- ❑ Physics: DVCS, excl. VM/PS prod. \rightarrow GPDs, parton imaging in b_T ; $g(x, Q^2, b_T)$
- ❑ Exclusivity \rightarrow large rapidity coverage \rightarrow rapidity gap events
 \searrow reconstruction of all particles in a given event
- ❑ high resolution, wide coverage in $t \rightarrow b_T \rightarrow$ Roman pots
- ❑ eA: veto nucleus breakup, determine impact parameter of collision
 \rightarrow acceptance for neutrons in ZDC



LEPTON KINEMATICS AND (X, Q^2) COVERAGE



Increasing lepton beam energy: scattered lepton is boosted to negative η

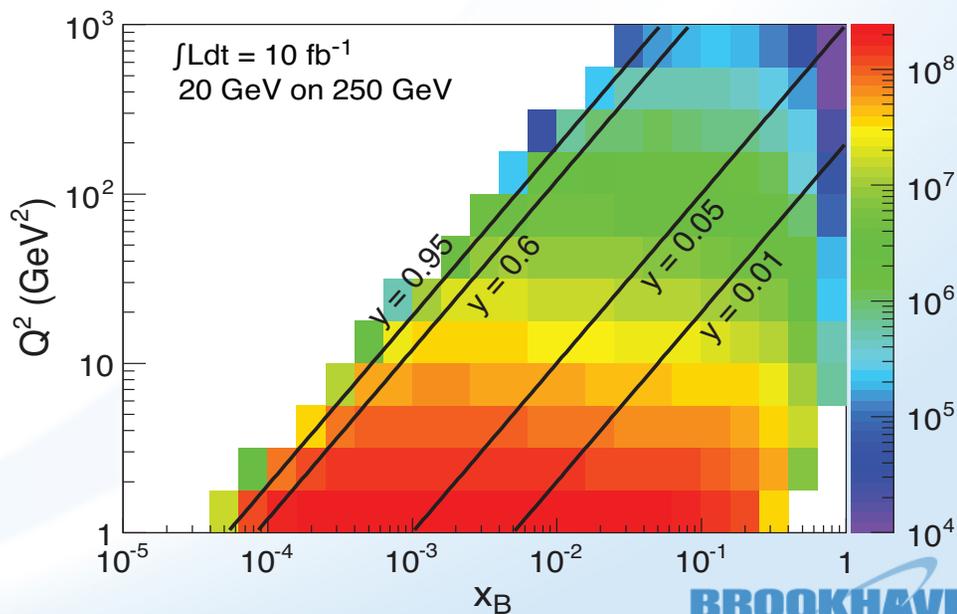
- $Q^2 > 1.0 \text{ GeV}^2$: rapidity coverage $-4 < \eta < 1$ is sufficient
- $Q^2 < 0.1 \text{ GeV}^2$: a dedicated low- Q^2 tagger is required

high y -coverage limited by radiative corrections

-> can be suppressed by requiring hadronic activity

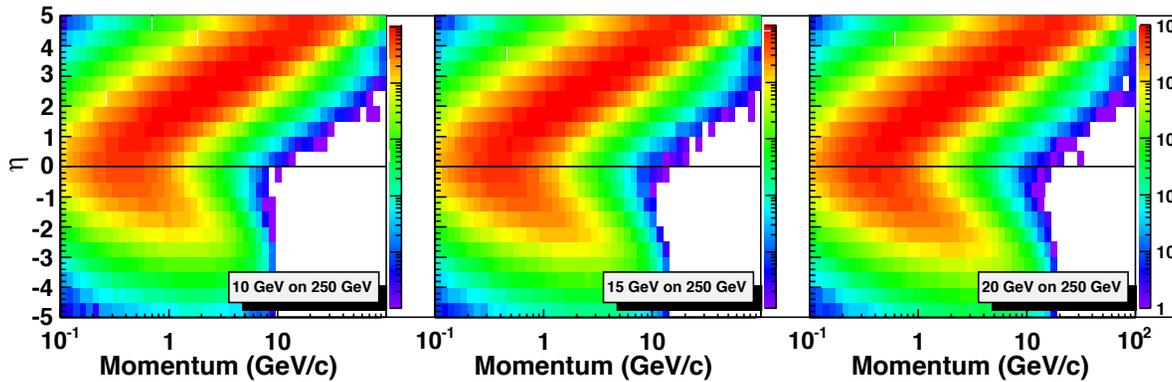
low y -coverage limited by E'_e resolution

-> use hadron or double angle method to reconstruct event kinematics

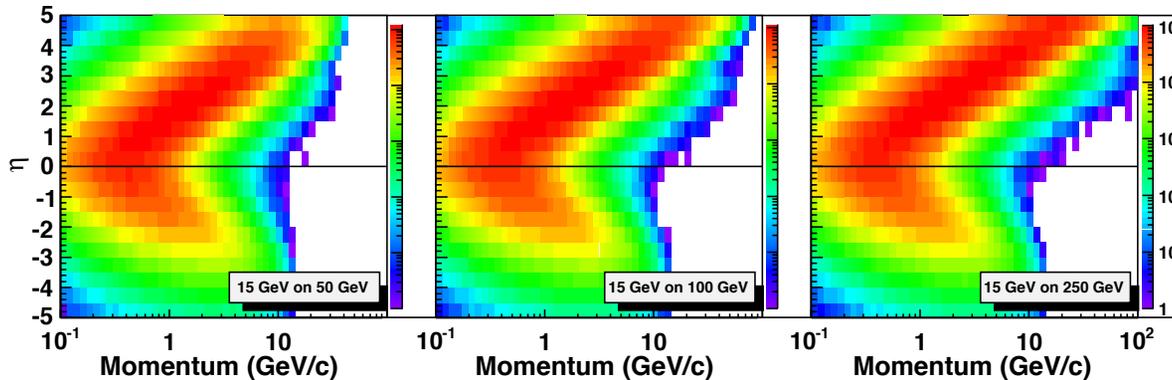


SIDIS: PION KINEMATICS

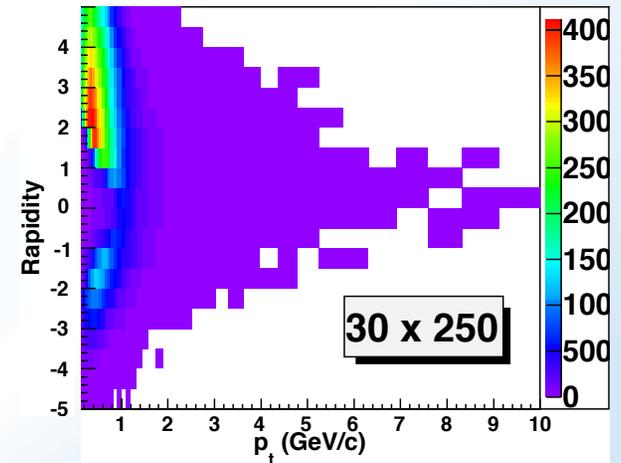
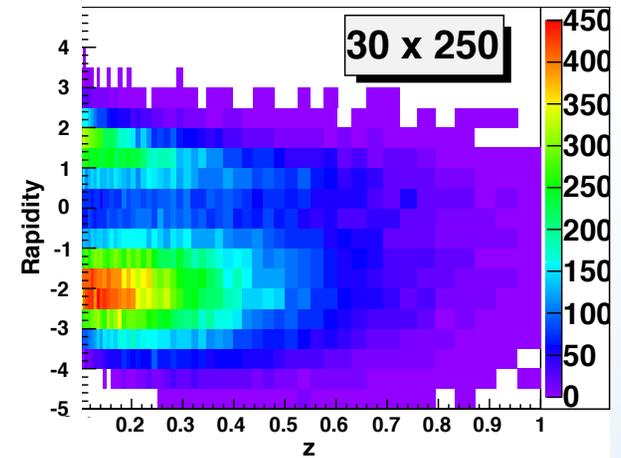
Cuts: $Q^2 > 1 \text{ GeV}^2$, $0.01 < y < 0.95$, $z > 0.1$



Increasing lepton beam energy boosts hadrons more to negative rapidity



Increasing hadron beam energy influences max. hadron energy at fixed η (and π^\pm , K^\pm , p^\pm look the same)



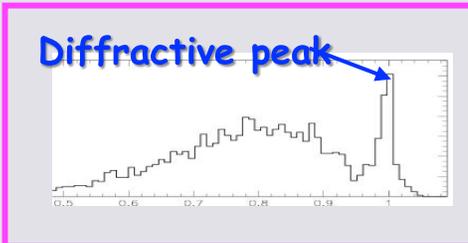
$-3 < \eta < 3$ covers entire p_t & z region important for physics

EXCLUSIVE REACTIONS

How can we select events: two methods

proton/neutron tag method

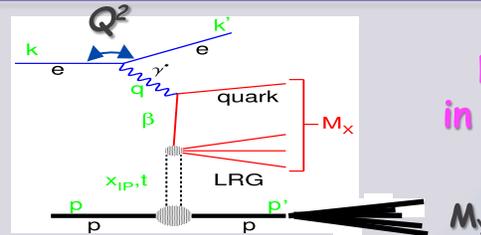
- Measurement of t
- Free of p-dissociation background
- High acceptance for Roman Pots / ZDC challenging
→ IR design



Need Roman Pot spectrometer and ZDC

Large Rapidity Gap method

- X system and e' measured
- Proton dissociation background
- High acceptance in η for detector



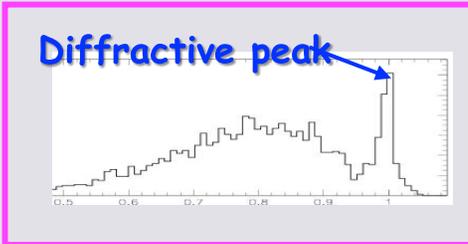
Need HCal in the forward region

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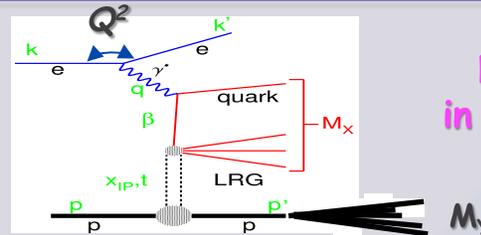
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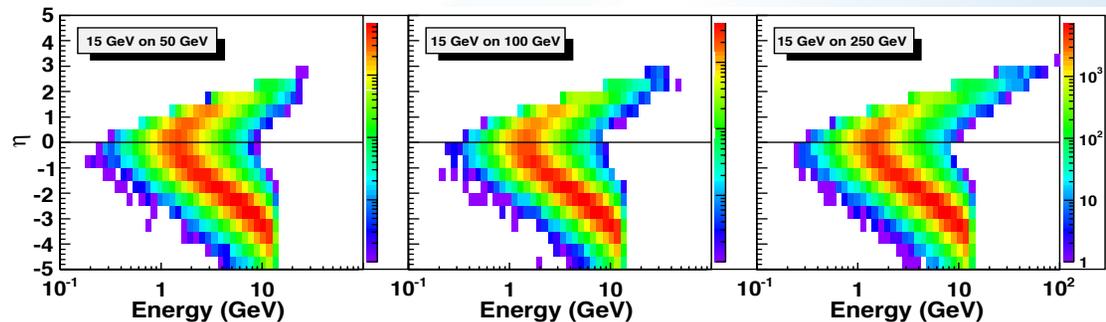
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Need HCal in the forward region

DVCS - photon kinematics

Cuts: $Q^2 > 1 \text{ GeV}$, $0.01 < y < 0.85$

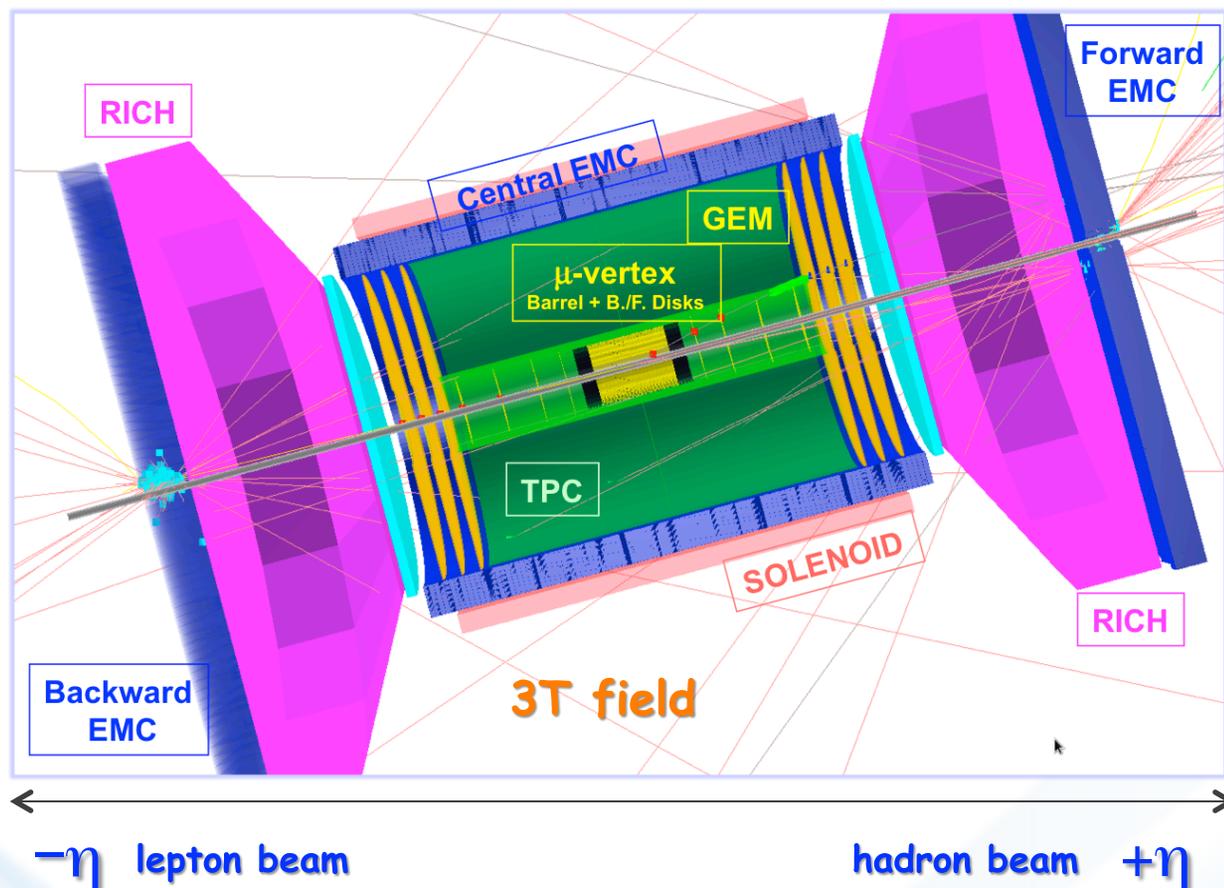


increasing Hadron Beam Energy: influences max. photon energy at fixed η - photons are boosted to negative rapidities (lepton direction)

Detector design

THE MODEL DETECTOR

-4 η <math>< 4</math>: Tracking & EM Calorimetry (hermetic coverage)



Lepton-ID:

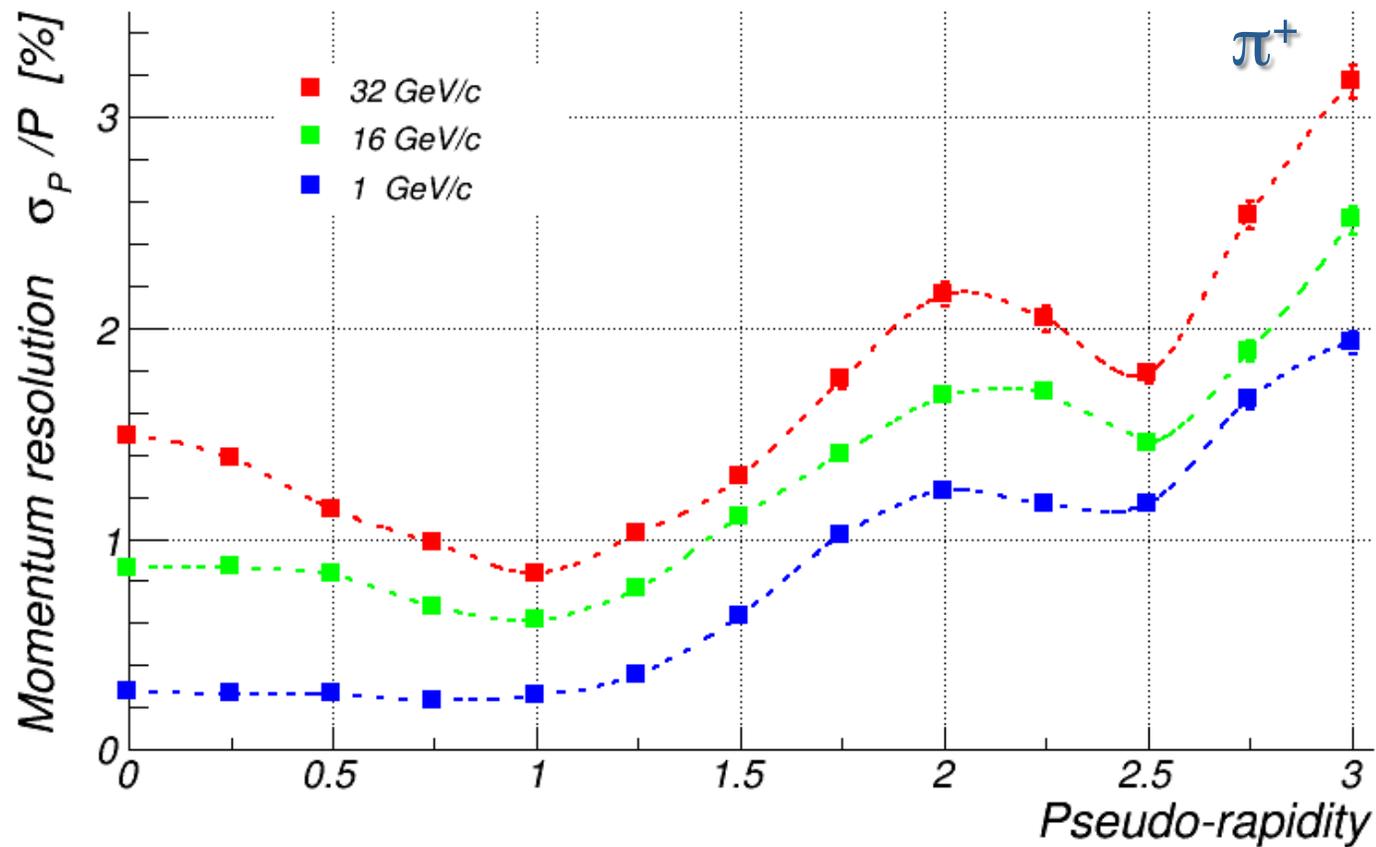
- 3 <math>< \eta < 3</math>: e/p
- 1 <math>< |\eta| < 3</math>: Hcal
- 3 <math>< |\eta| < 4</math>: Ecal & Hcal
- $|\eta| < 4</math>: γ suppression via tracking$

PID:

- 1 <math>< |\eta| < 3</math>: RICH
- 1 <math>< \eta < 1</math>: TPC (dE/dx)

-> other PID options at central rapidities possible: DIRC, Time-of-Flight, proximity focusing Aerogel-RICH, ...

TRACKER MOMENTUM RESOLUTION

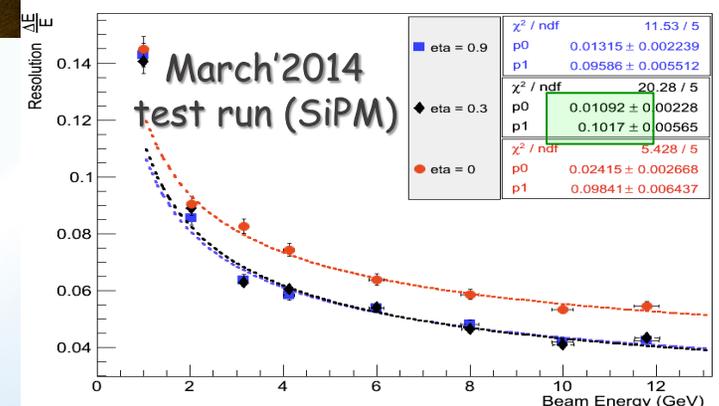
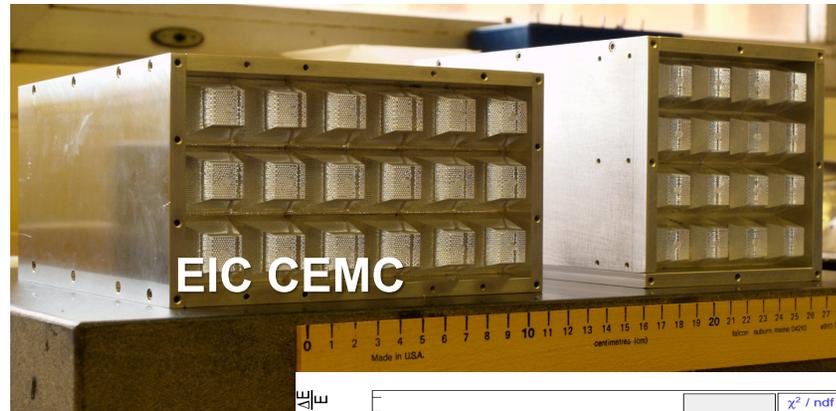
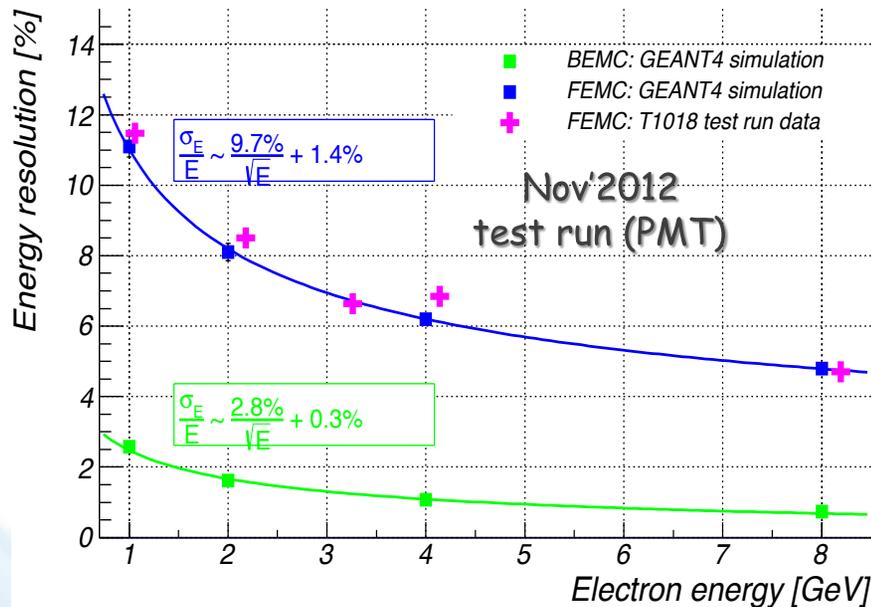


-> expect 2-3% or better momentum resolution in the whole kinematic range

EM CALORIMETER ENERGY RESOLUTION

The setup:

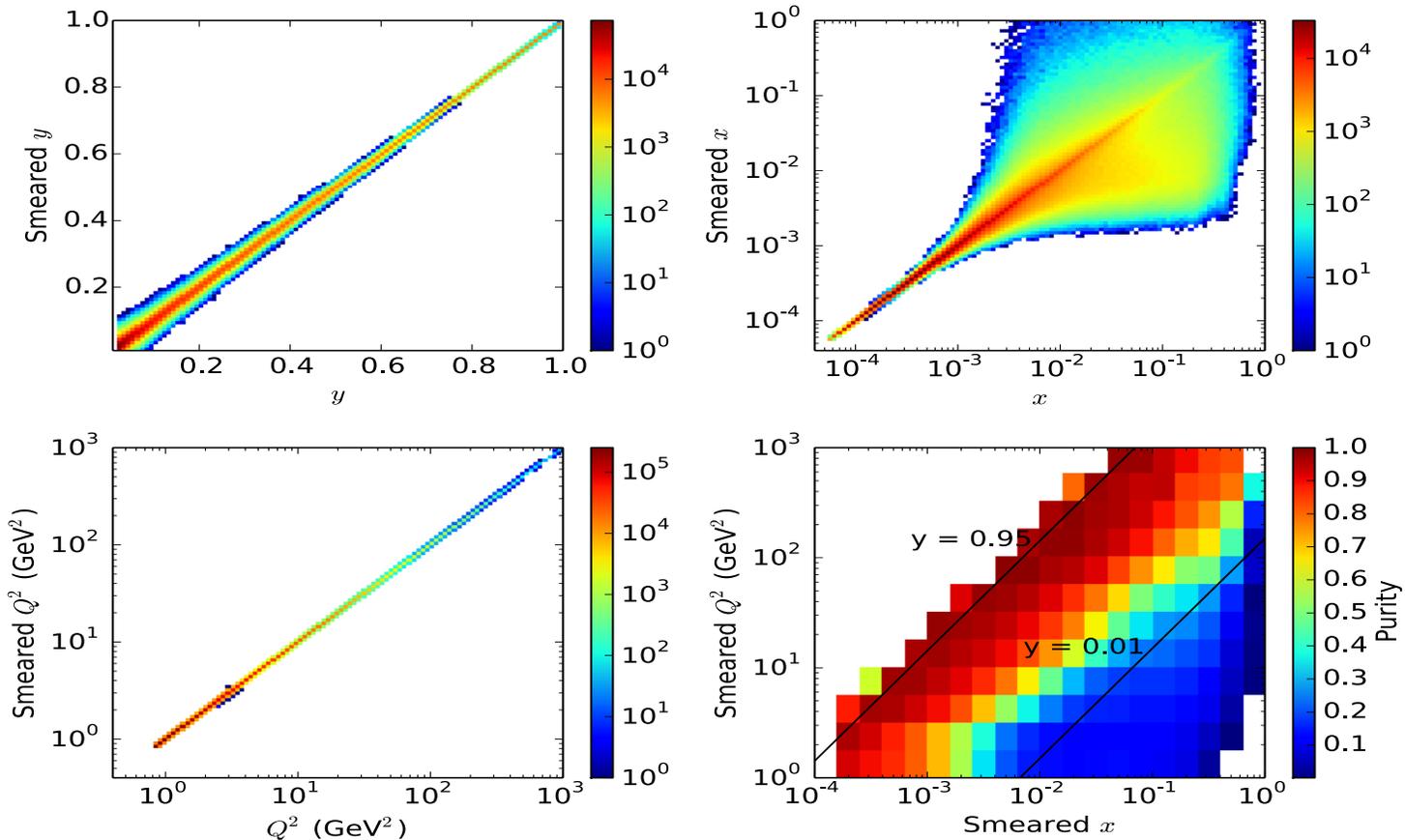
- Forward - FEMC - ($\eta > 1$): tungsten powder scintillating fiber sampling technology (STAR calorimeter upgrade)
- Central - CEMC - ($-1 < \eta < 1$): same as forward, but tapered towers
- Backward - BEMC - ($\eta < -1$): PWO crystals (~PANDA design)



-> reasonable agreement between GEANT simulation and test run data for FEMC/CEMC prototypes

RESOLUTION IN KINEMATICS VARIABLES

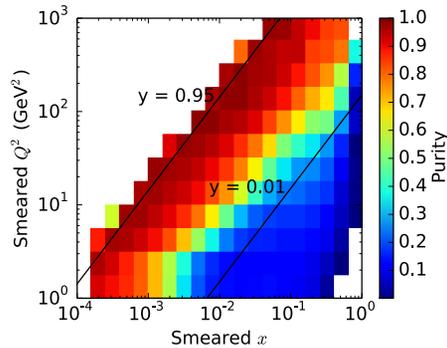
all plots here and next page for 15 GeV on 250 GeV



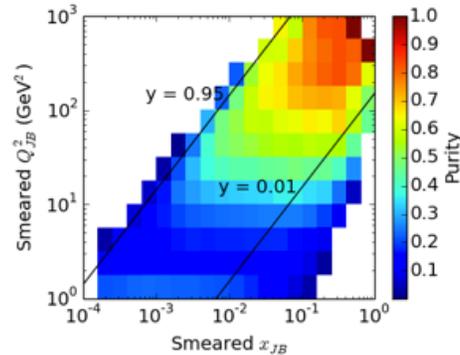
-> very moderate smearing

RESOLUTION IN KINEMATICS VARIABLES & PID

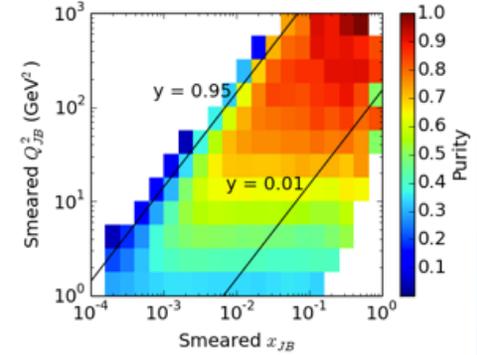
electron method



hadron method:



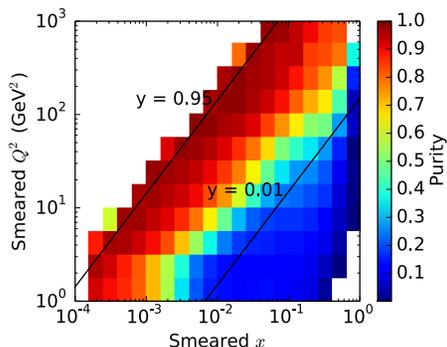
DA method:



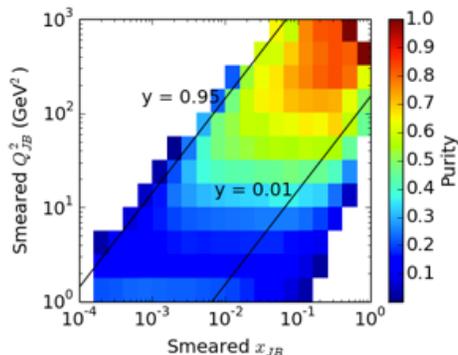
high $Purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$ important to
unfold measured quantities to Born level

RESOLUTION IN KINEMATICS VARIABLES & PID

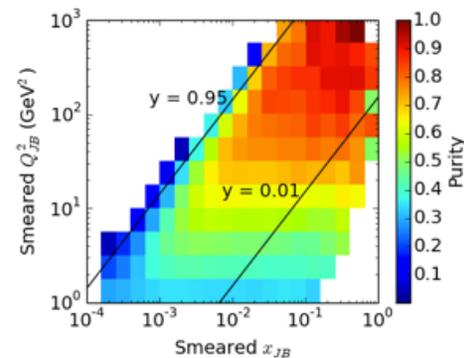
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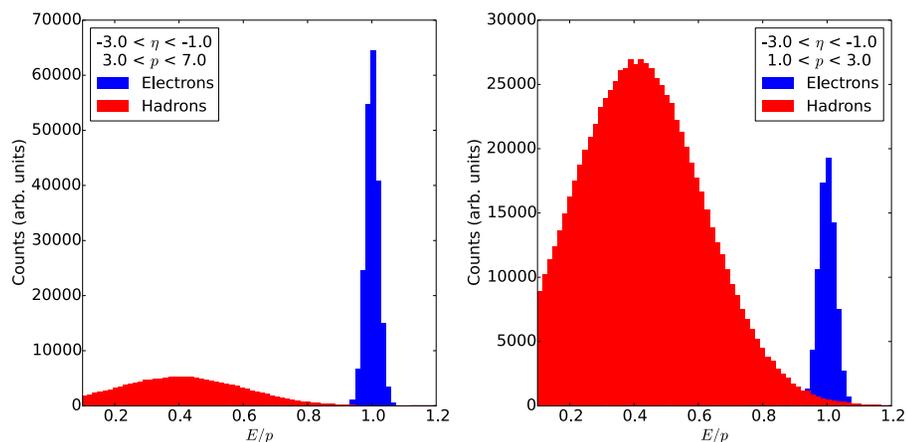
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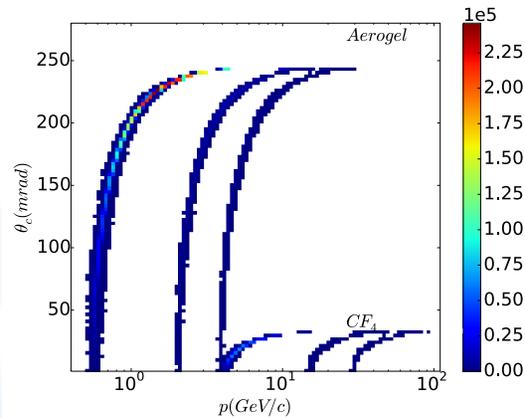
$$\text{high Purity} = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}} \text{ important to}$$

unfold measured quantities to Born level

Electron PID: E/p



Hadron PID: RICH



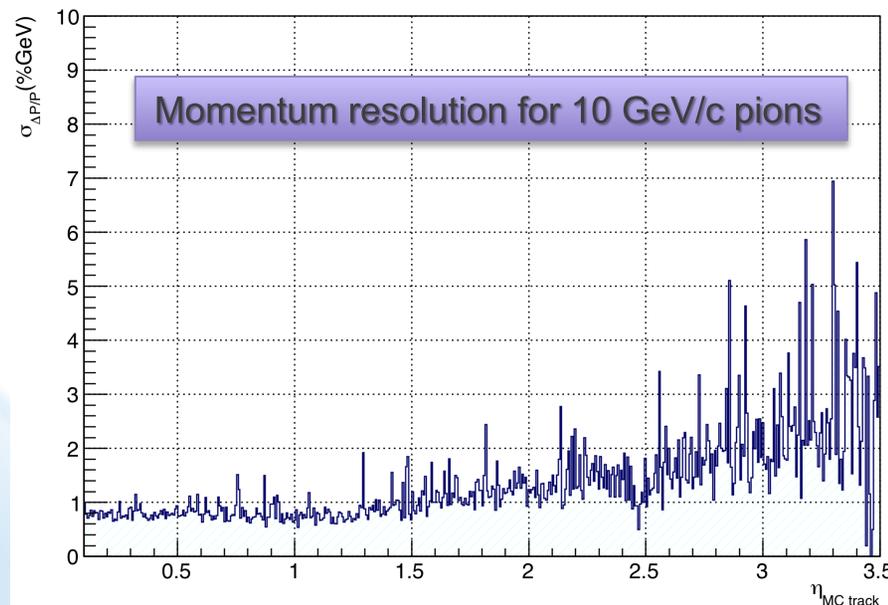
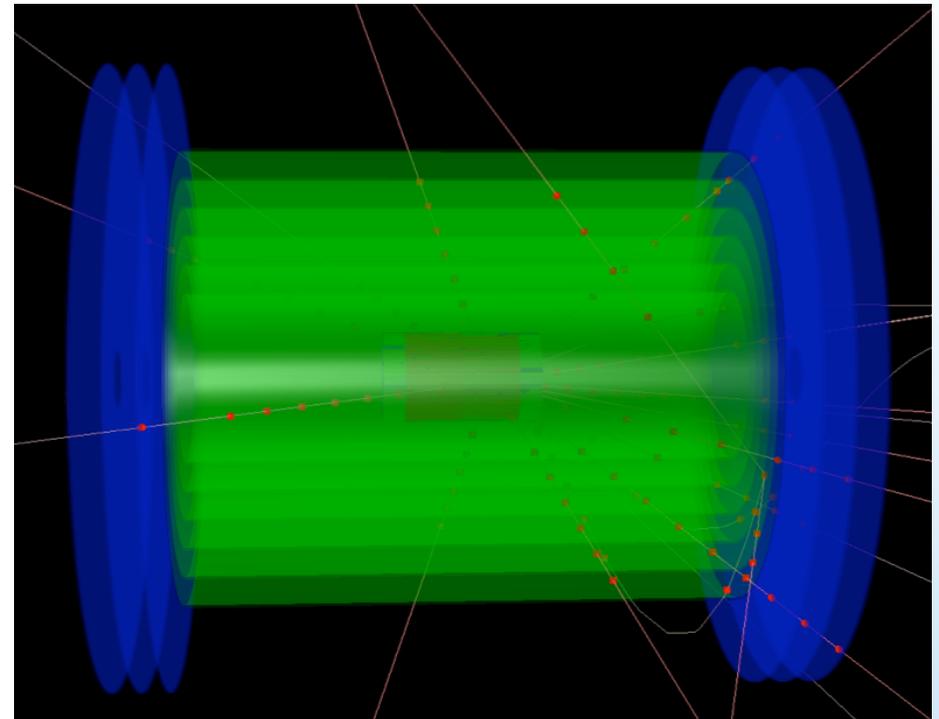
momentum resolution is critical for RICH performance
 → (no photon detector resolution accounted here)

ALTERNATIVE TRACKER CONFIGURATION

by Maxence Vandenbroucke

- 1) use cylindrical micromegas instead of TPC
- 2) add forward GEM disks at high rapidity

- o 6 barrels from 20cm to 80cm radii
- o 2 chambers per barrel (2D readout)
- o 200 μ m spatial resolution



-> looks like a realistic solution

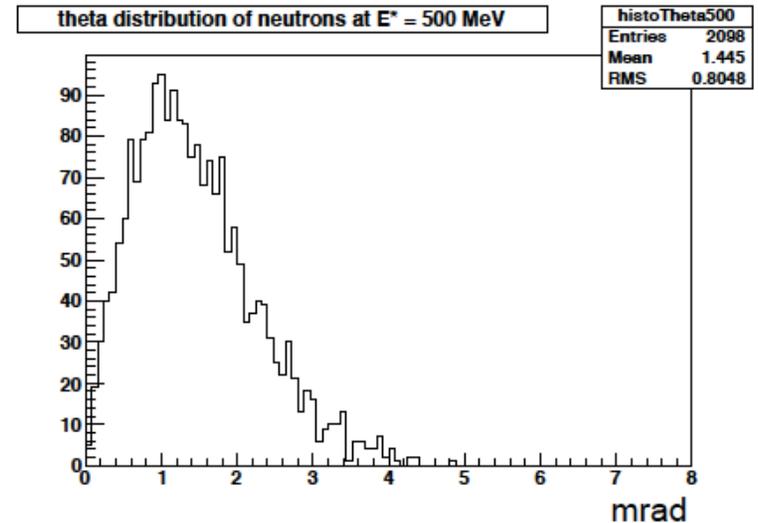
IR design

REQUIREMENTS FROM PHYSICS

Neutrons from 50GeV/n Au break up

Hadron-going direction:

1. detection of neutrons from nuclear break up
→ location/acceptance of ZDC (<4 mrad)
2. detection of scattered protons from exclusive and diffractive reactions;
→ location/acceptance of RP (<5 mrad):

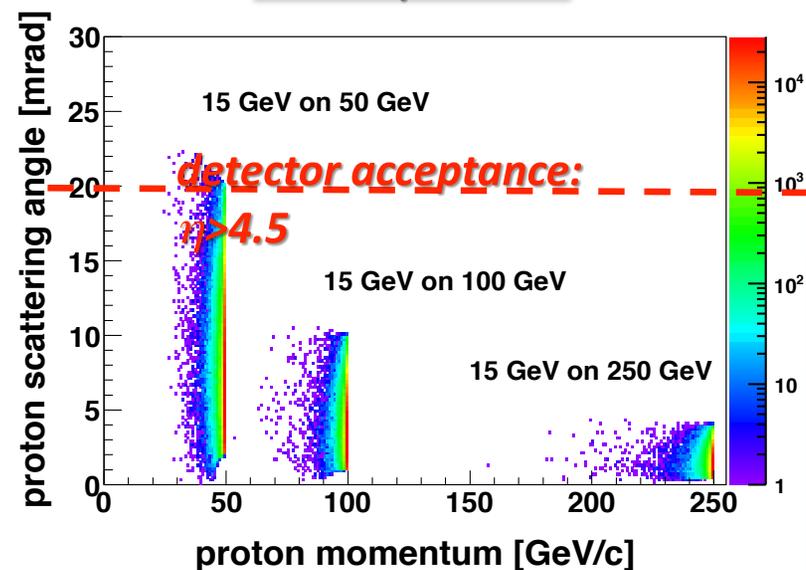


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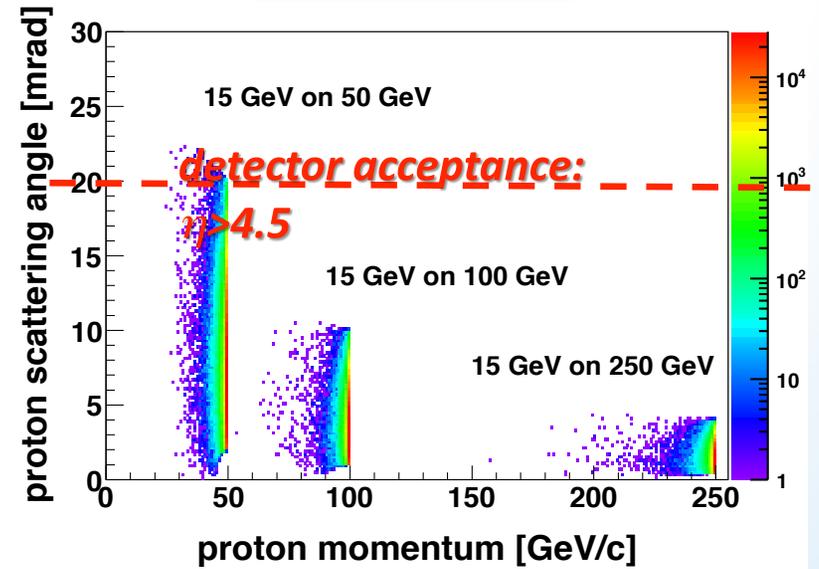


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3. beam element free region around the IR
4. minimize impact of detector magnetic field on lepton beam
→ synchrotron radiation

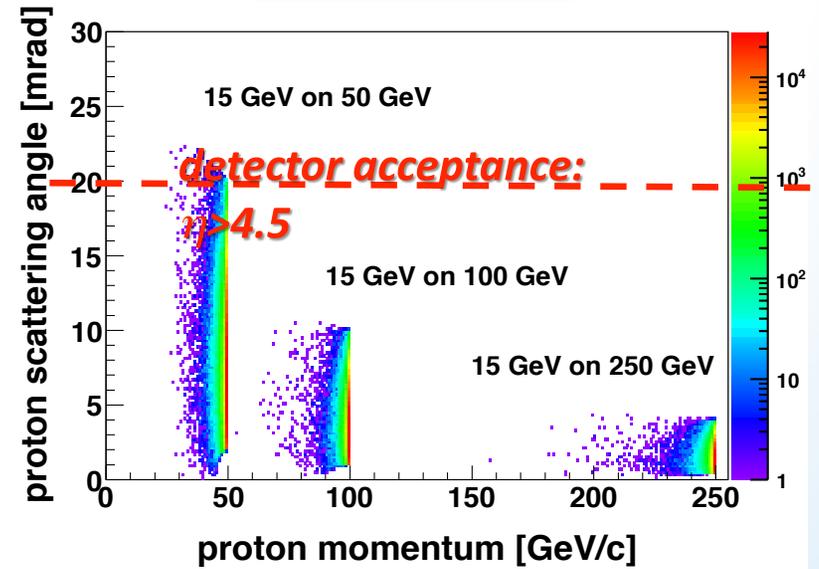


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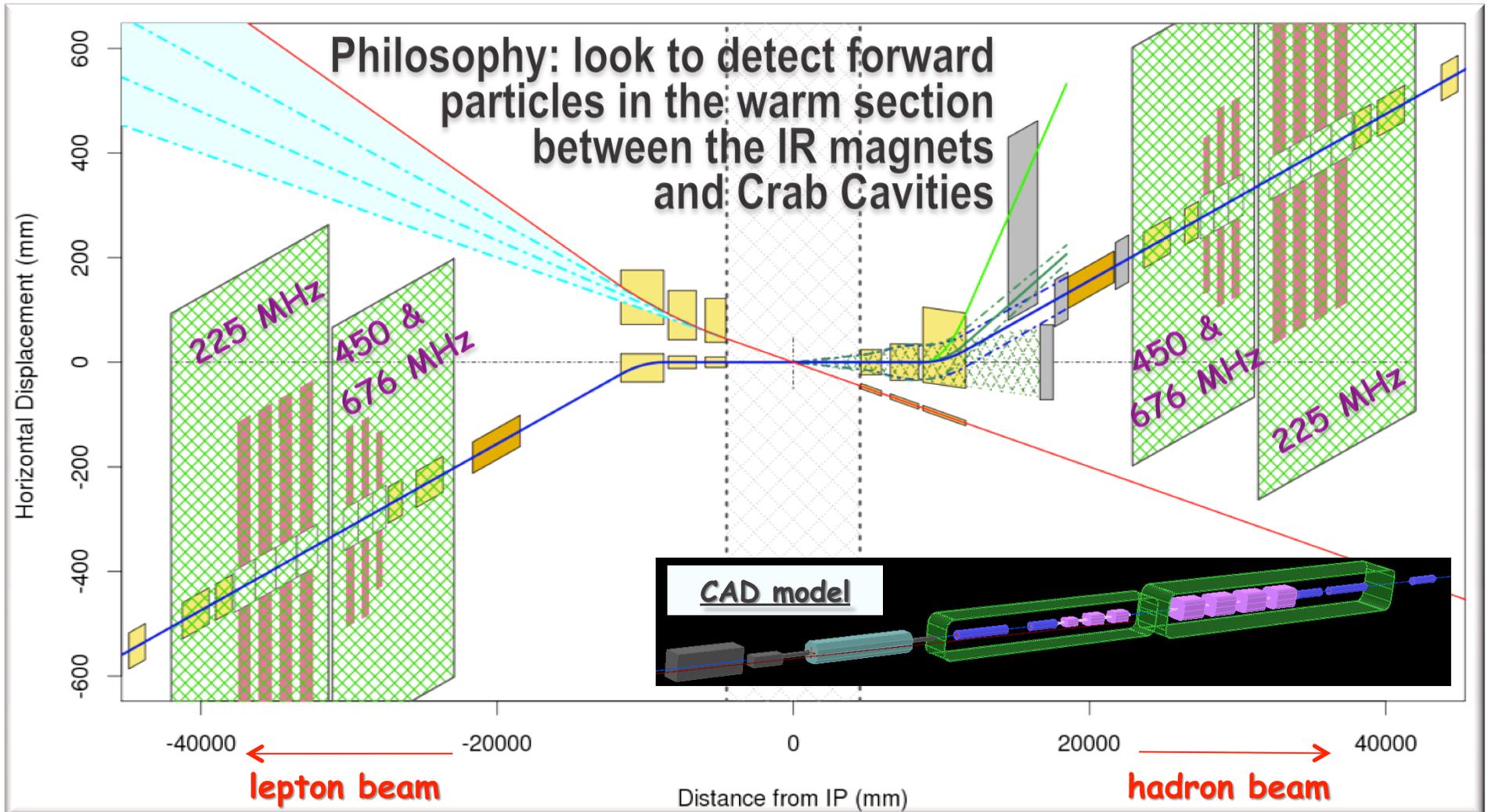


Lepton-going direction:

1. space for low Q^2 scattered lepton detection
2. space for the luminosity monitor in the outgoing lepton beam direction
3. space for lepton polarimeter

PRESENT IR LAYOUT

by Brett Parker



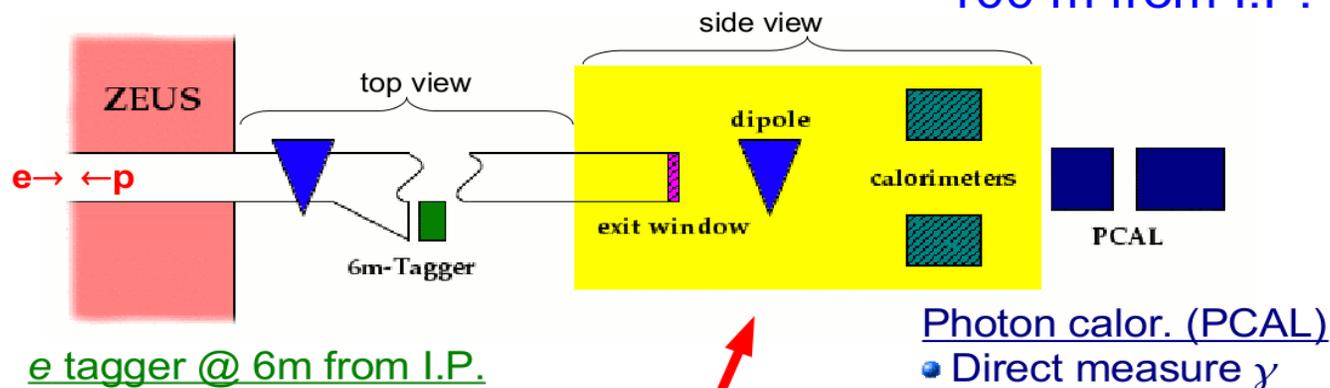
LUMINOSITY MONITOR

□ Concept:

- Use Bremsstrahlung $ep \rightarrow e\gamma$ as a reference cross section
- normally only γ is measured -> will hardly work at EIC luminosity!

ZEUS LUMI system: 2 γ detectors

~100 m from I.P.



e tagger @ 6m from I.P.

- Measure scattered e
- W-scint. spaghetti calor.
- Check photon accept. (work in progress...)
- Also for physics: tag high W photoprod.
- Not discussed more here...

Pair spectrometer

- Measure pairs from $\gamma \rightarrow e^+e^-$ in exit window

Photon calor. (PCAL)

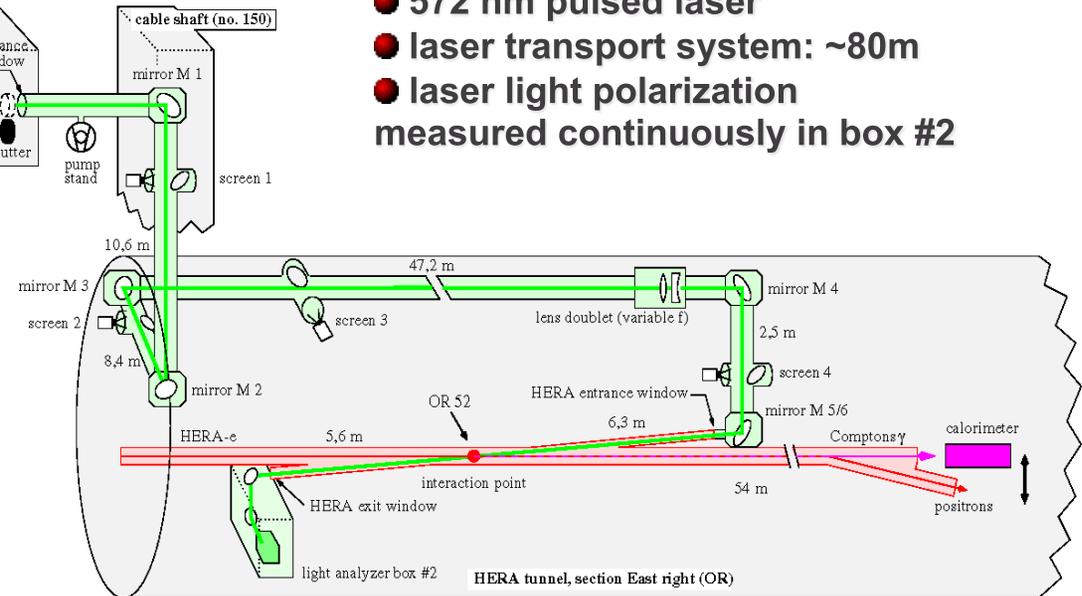
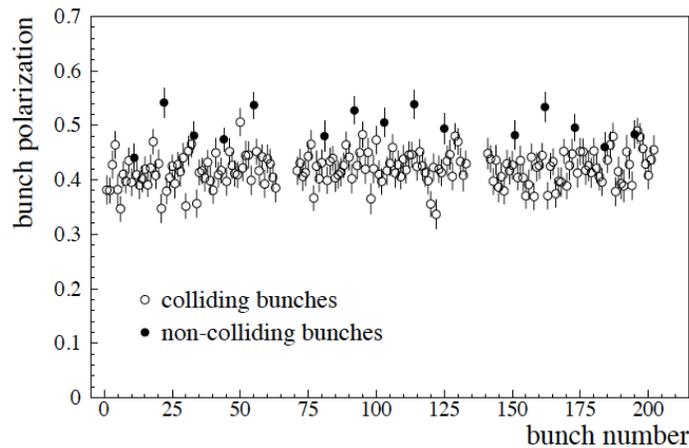
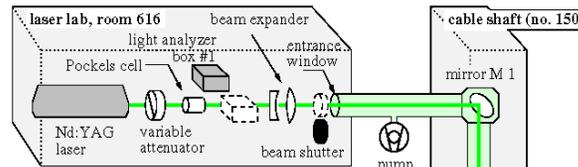
- Direct measure γ

3

LEPTON POLARIMETER

Method: Compton backscattering

- 572 nm pulsed laser
- laser transport system: ~80m
- laser light polarization measured continuously in box #2

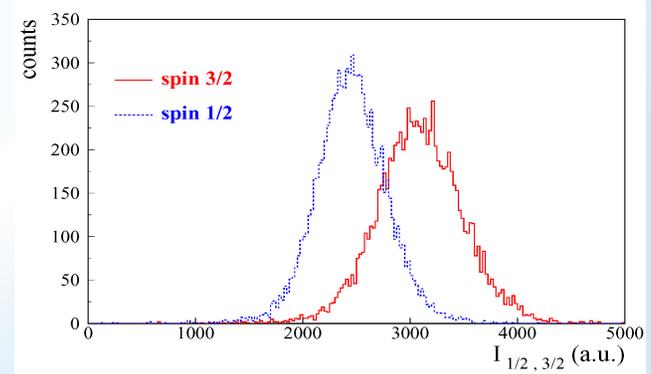


$$A_m = (I_{3/2} - I_{1/2}) / (I_{3/2} + I_{1/2})$$

$$= P_e P_\lambda A_p; \quad A_p = 0.184$$

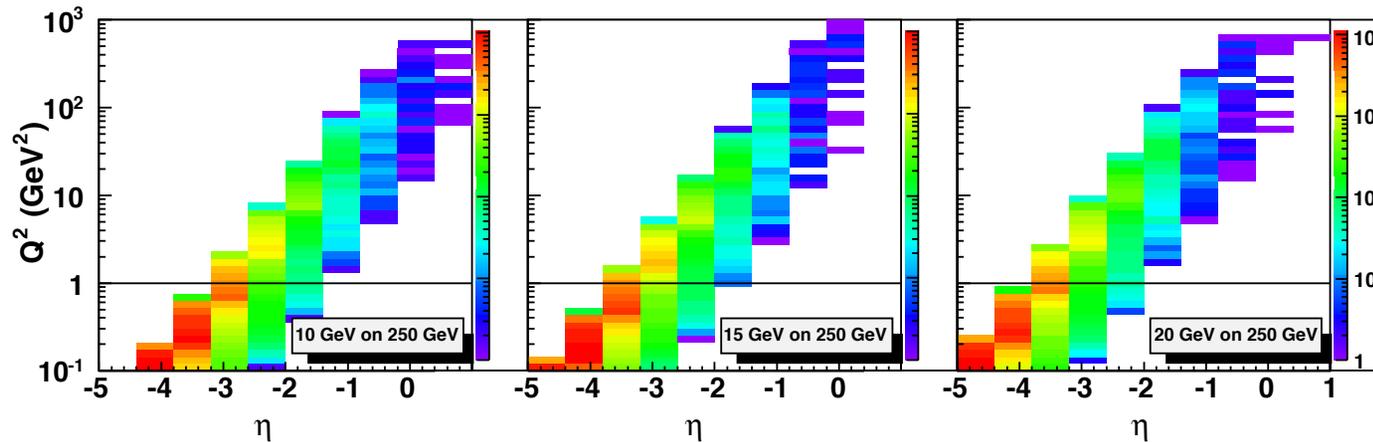
Multi-Photon Mode:

- eff. independent of bremsstrahlung background
- $dP/P \sim 0.01$ in 1 min



LOW Q^2 -TAGGER

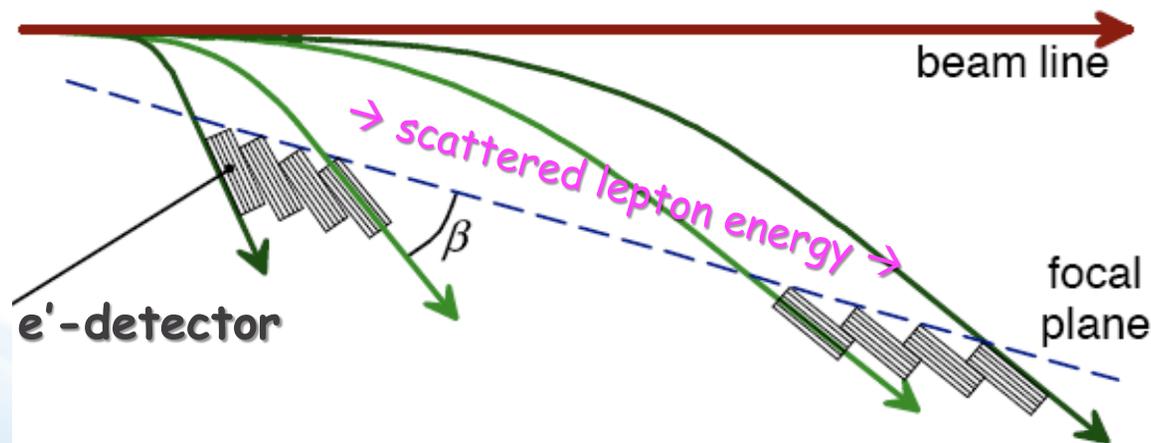
- Task: detect low Q^2 scattered electrons
→ quasi-real photoproduction physics



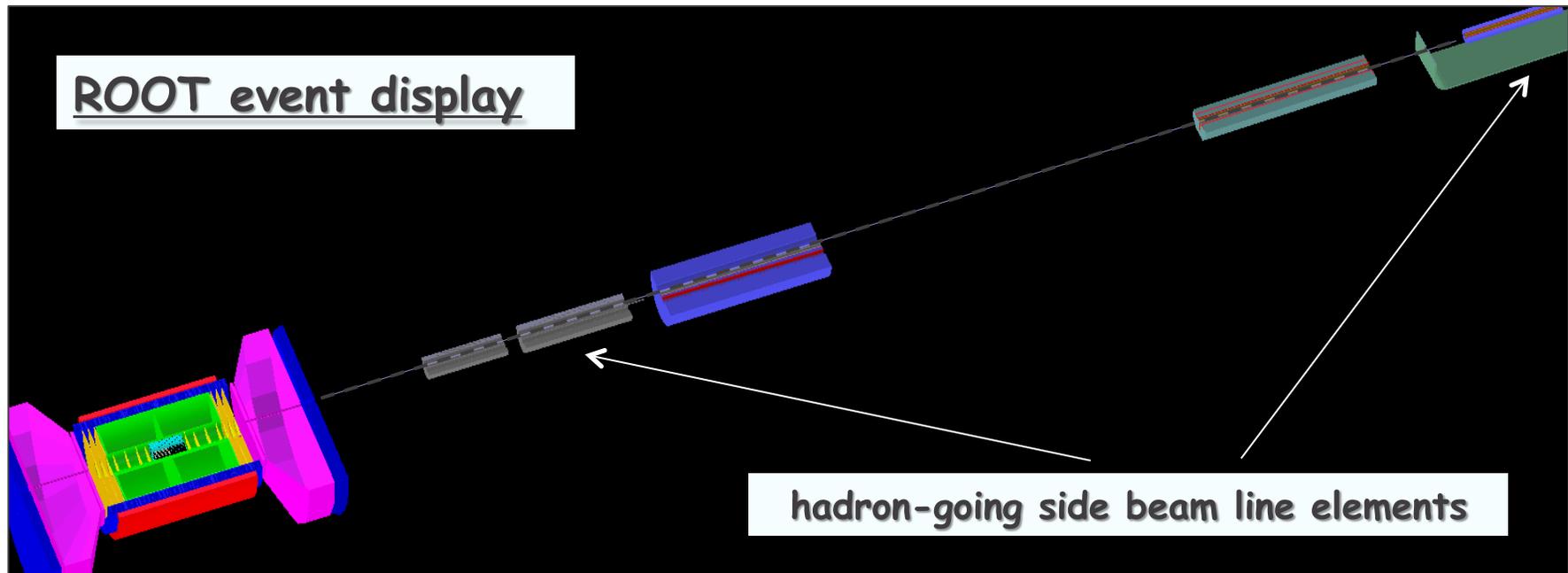
DIS electron kinematics

→ at nominal energy can not register scattered electrons with $Q^2 < 0.1$ in main spectrometer!

- need a separate device designed similar to the JLab Hall D tagger (finely spaced scintillator array):

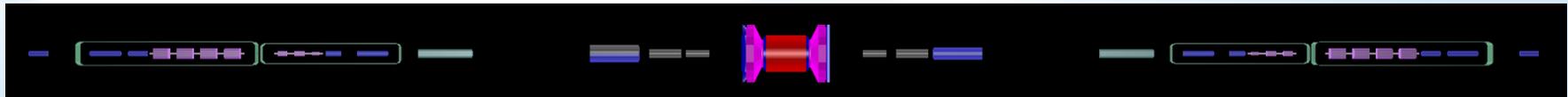


GEANT SIMULATION SETUP



Goals:

- Directly import CAD files
- Import magnetic field maps
- Implement Roman Pots, ZDC, Lumi Monitor, Electron Polarimeter



-> work in progress ...

SUMMARY

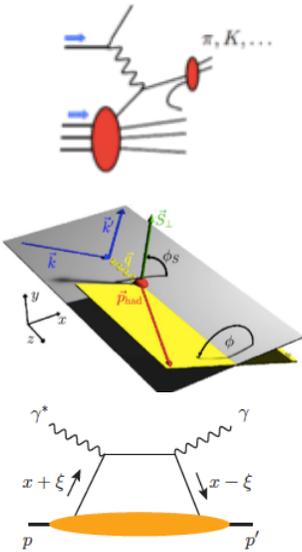
- Established and documented requirements from physics on the detector and IR design
 - https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements
 - https://wiki.bnl.gov/eic/index.php/IR_Design_Requirements
- Performed design studies on a model eRHIC detector
 - tracker
 - calorimeters
- Working hand-in-hand with CAD to integrate into the IR design
 - Roman Pots
 - Zero Degree Calorimeter
 - low Q^2 tagger
 - luminosity detector
 - electron polarimeter

Backup

Physics requirements

WHAT IS NEEDED TO REALIZE EIC PROGRAM

experimental program to address these questions:



inclusive and semi-inclusive DIS

longitudinal motion of spinning quarks and gluons

azimuthal asymmetries in DIS

adds their transverse momentum dependence

exclusive processes

adds their transverse position

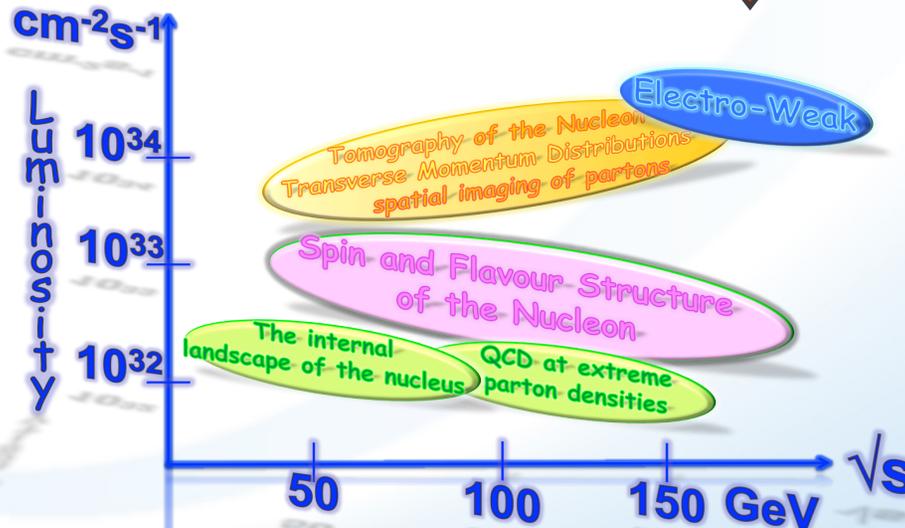
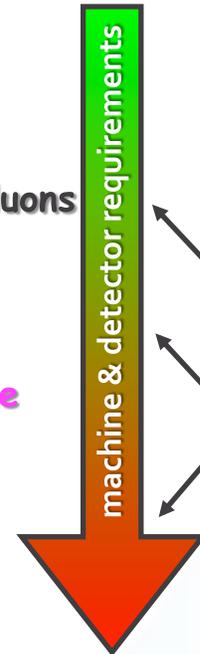
prerequisites

all need $\sqrt{s_{ep}} > 50 \text{ GeV}$
to access $x < 10^{-3}$ where
sea quarks and gluons
dominate

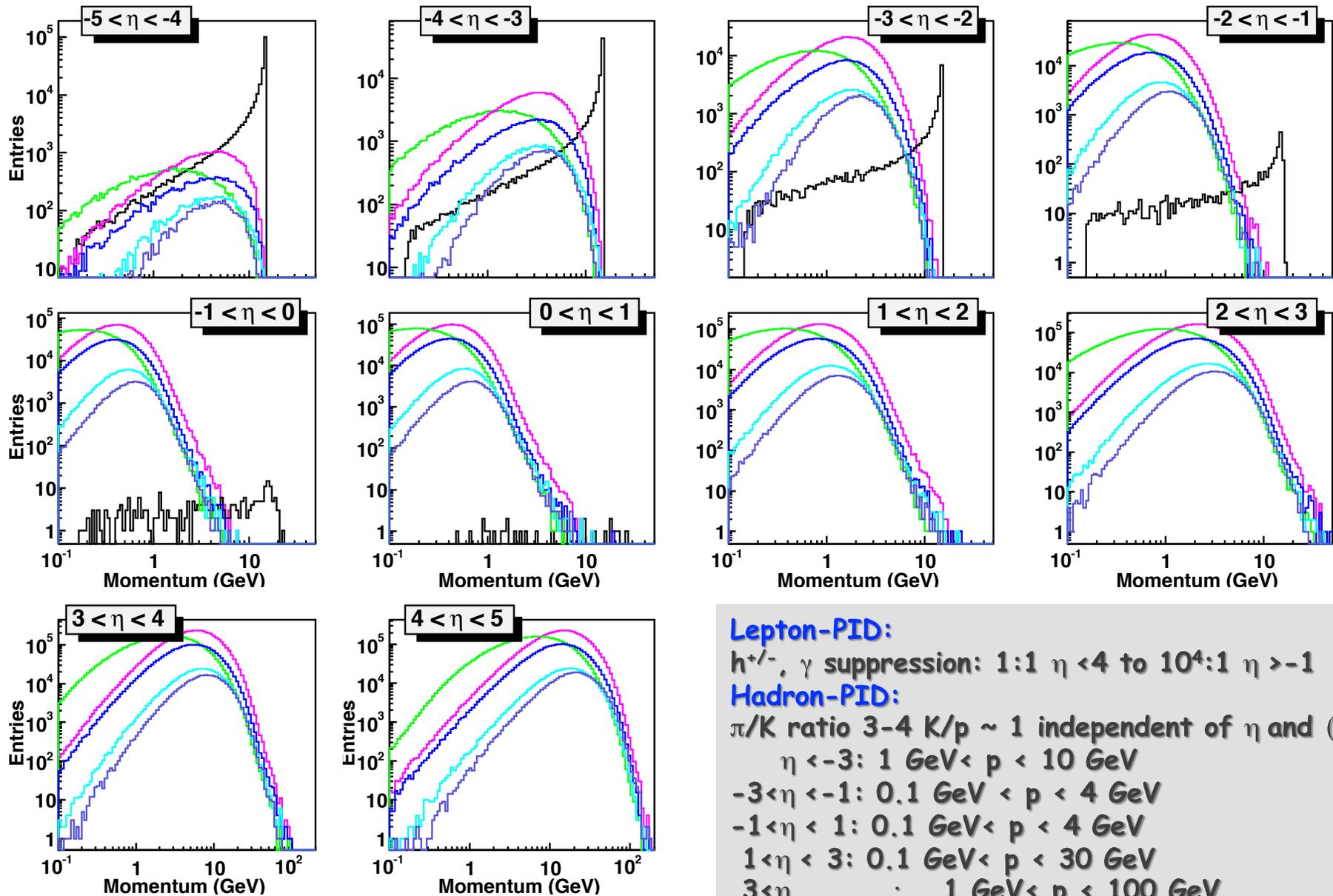
$$\mathcal{L} \simeq 10 \text{ fb}^{-1}$$

$$\mathcal{L} = 10 \div 100 \text{ fb}^{-1}$$

- multi-dimensional binning
- to reach $k_T > 1 \text{ GeV}$
- to reach $|t| > 1 \text{ GeV}^2$



PID REQUIREMENTS



Lepton-PID:

$h^{+/-}, \gamma$ suppression: 1:1 $\eta < 4$ to $10^4:1$ $\eta > -1$

Hadron-PID:

π/K ratio 3-4 $K/p \sim 1$ independent of η and (\sqrt{s})

$\eta < -3$: $1 \text{ GeV} < p < 10 \text{ GeV}$

$-3 < \eta < -1$: $0.1 \text{ GeV} < p < 4 \text{ GeV}$

$-1 < \eta < 1$: $0.1 \text{ GeV} < p < 4 \text{ GeV}$

$1 < \eta < 3$: $0.1 \text{ GeV} < p < 30 \text{ GeV}$

$3 < \eta$: $1 \text{ GeV} < p < 100 \text{ GeV}$

→ impact on PID technology

Detector design

TRACKING ELEMENTS

vertex silicon tracker:

- ❑ 6 layers at [30..160] mm radius
- ❑ 0.37% X_0 in acceptance per layer
- ❑ digitization: discrete $\sim 20 \times 20 \mu\text{m}^2$ pixels

forward/backward silicon trackers:

- ❑ 2x7 disks with up to 180 mm radius
- ❑ N sectors per disk; 200 μm silicon-equivalent thickness
- ❑ digitization: discrete $\sim 20 \times 20 \mu\text{m}^2$ pixels

TPC:

- ❑ $\sim 2\text{m}$ long; gas volume radius [200..800] mm
- ❑ 1.2% X_0 IFC, 4.0% X_0 OFC; 15.0% X_0 aluminum end-caps
- ❑ digitization: assume 5 mm GEM pads

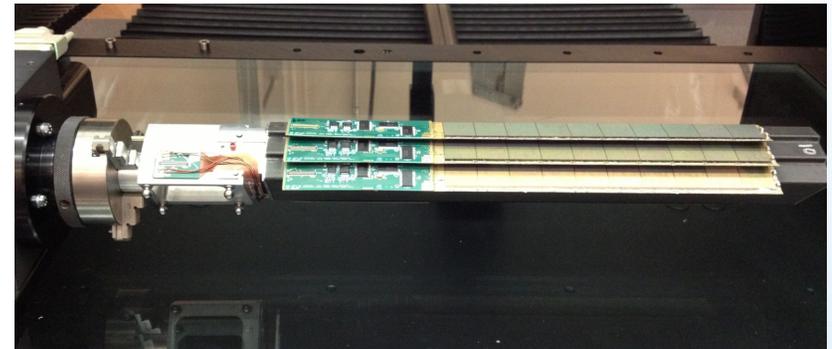
GEM trackers:

- ❑ 3 disks behind the TPC end-caps
- ❑ STAR FGT design
- ❑ digitization: 100 μm resolution in X&Y (gaussian)

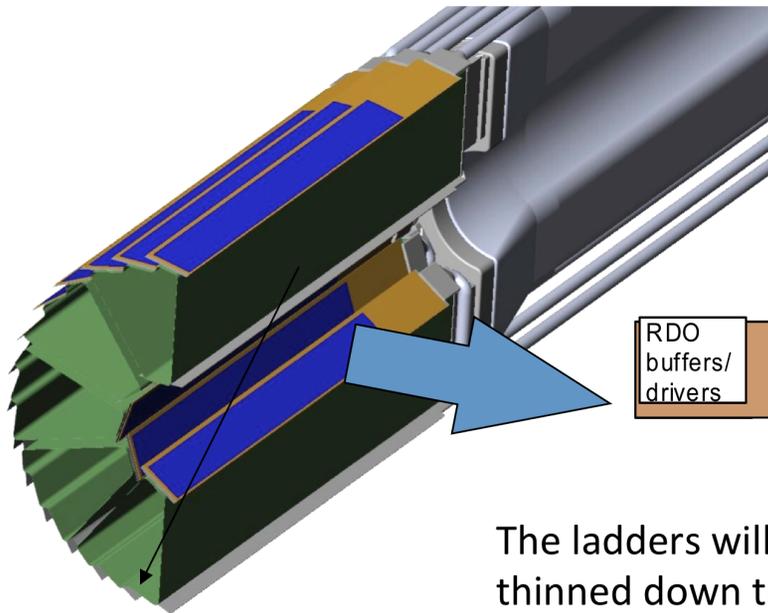
VERTEX SILICON TRACKER

- STAR detector upgrade “building blocks” (cable assemblies)

Carbon fiber sector tubes (~ 200 μ m thick)



Ladder with 10 MAPS sensors (~ 2x2 cm each)



RDO
buffers/
drivers

MAPS

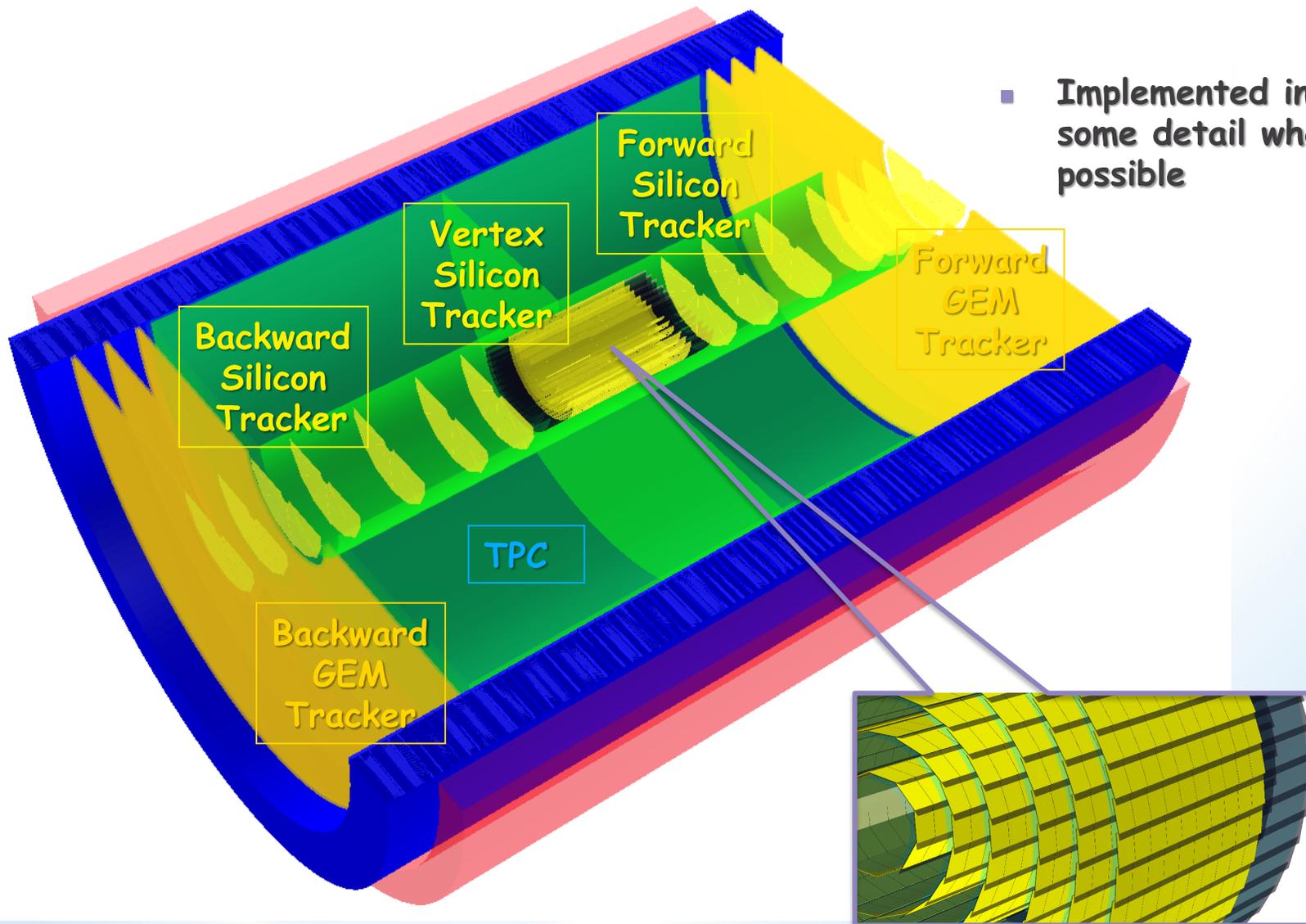
Aluminum conductor Ladder Flex Cable

20 cm

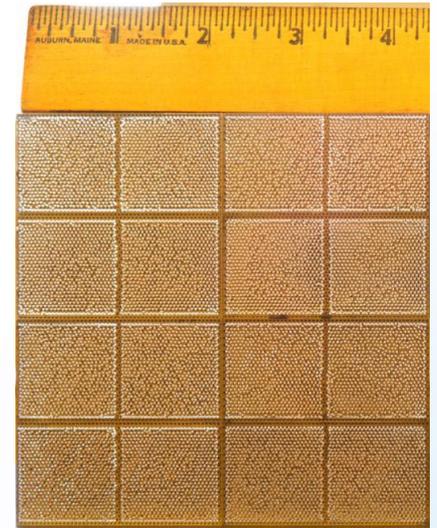
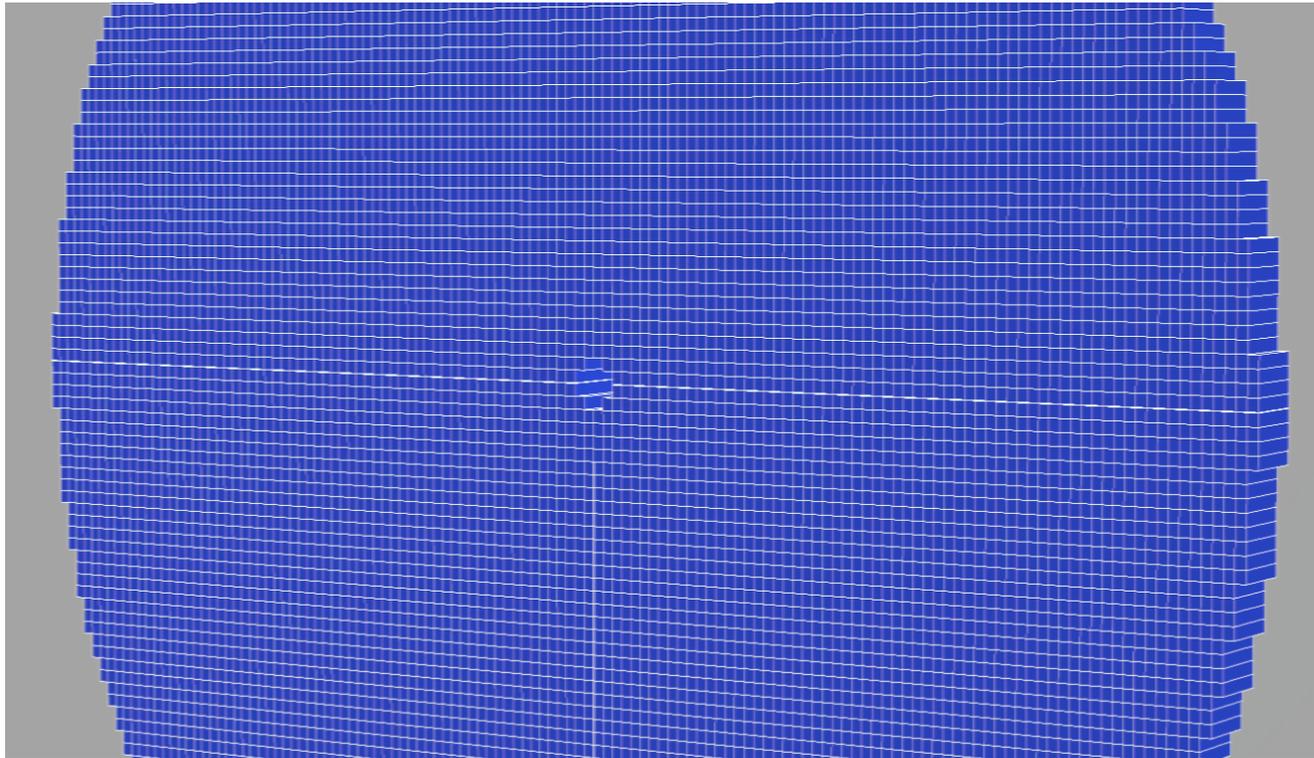
The ladders will be instrumented with sensors
thinned down to 50 micron Si.

TRACKER VIEW IN EICROOT SIMULATION

- Implemented in quite some detail whenever possible

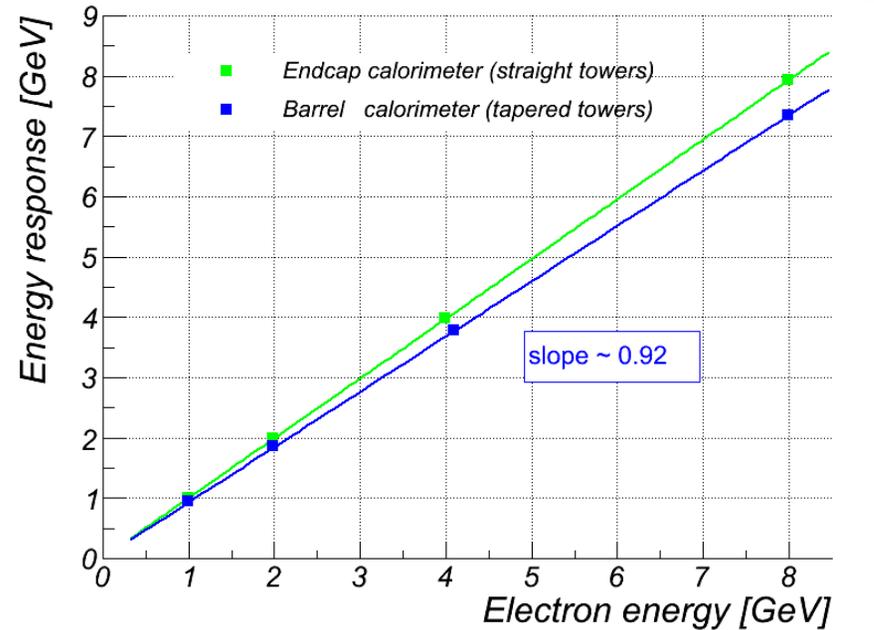
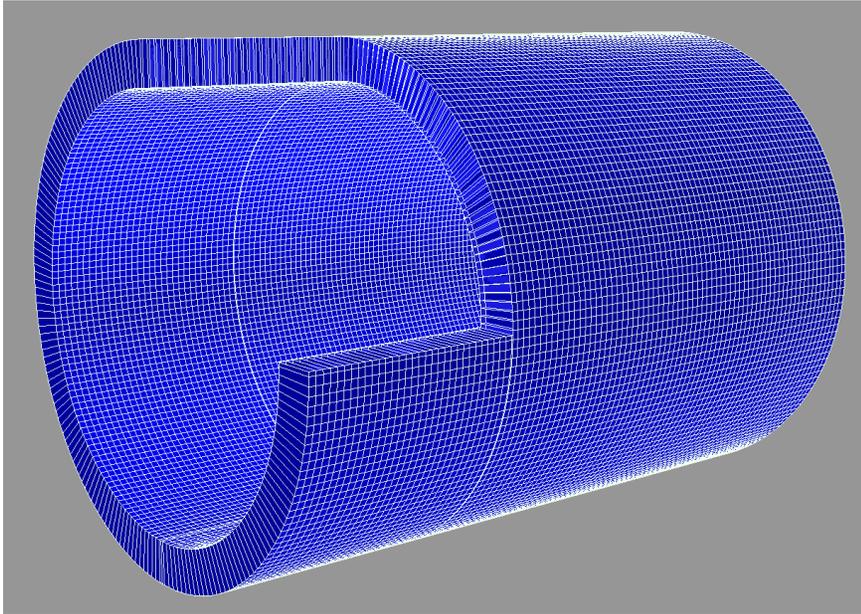


FORWARD EM CALORIMETER (FEMC)



- STAR EM calorimeter upgrade building blocks (tungsten powder scintillating fiber sampling technology)
- 0.5mm fibers; sampling fraction for EM showers $\sim 2.6\%$
- +2500mm from the IP; non-projective geometry

CENTRAL EM CALORIMETER (CEMC)



-> barrel (central) calorimeter collects less light, but response (at a fixed 3° angle) is perfectly linear

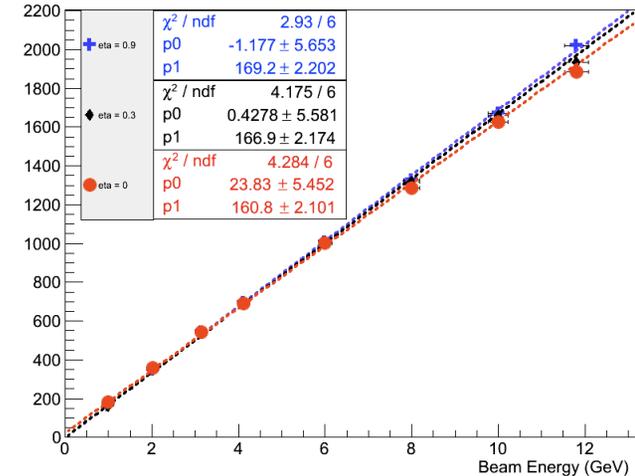
- same tungsten powder + fibers technology as FEMC, ...
- ... but towers are tapered
- non-projective geometry; radial distance from beam line [815 .. 980]mm

-> simulation does not show any noticeable difference in energy resolution between straight and tapered tower calorimeters

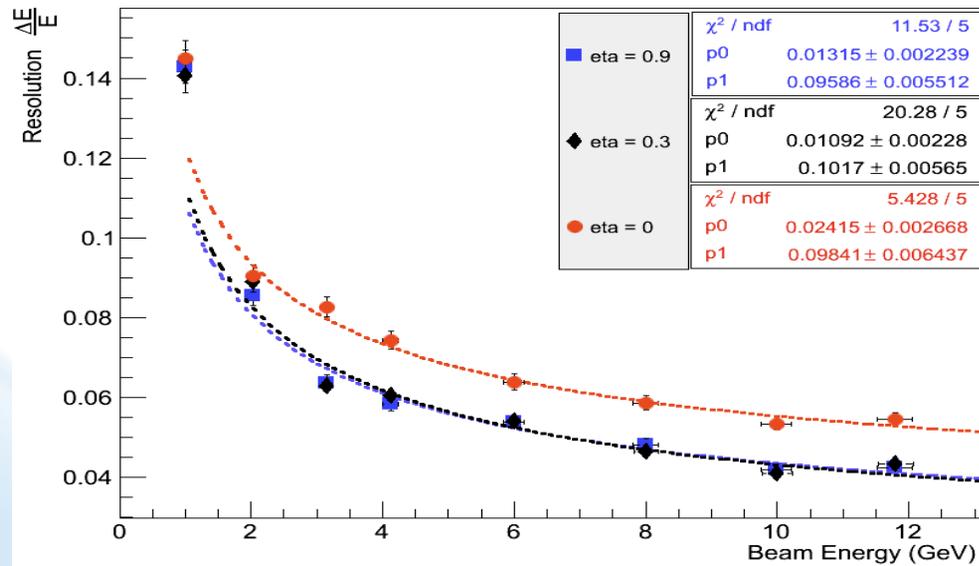
PRELIMINARY DATA FROM MARCH'2014 RUN



EIC BEMC Linearity. $0 < \eta < 0.9$



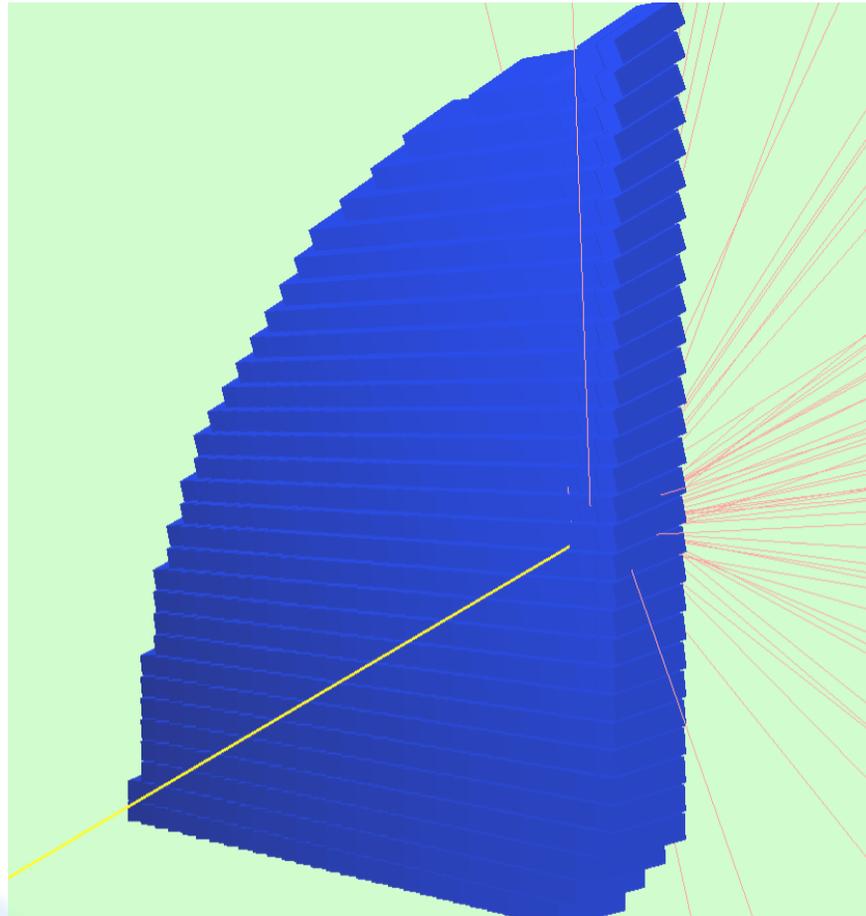
EIC BEMC at eta=0.9, 0.3, 0, Energy Resolution



- linear response
- high light output
- good resolution (for central tower area)

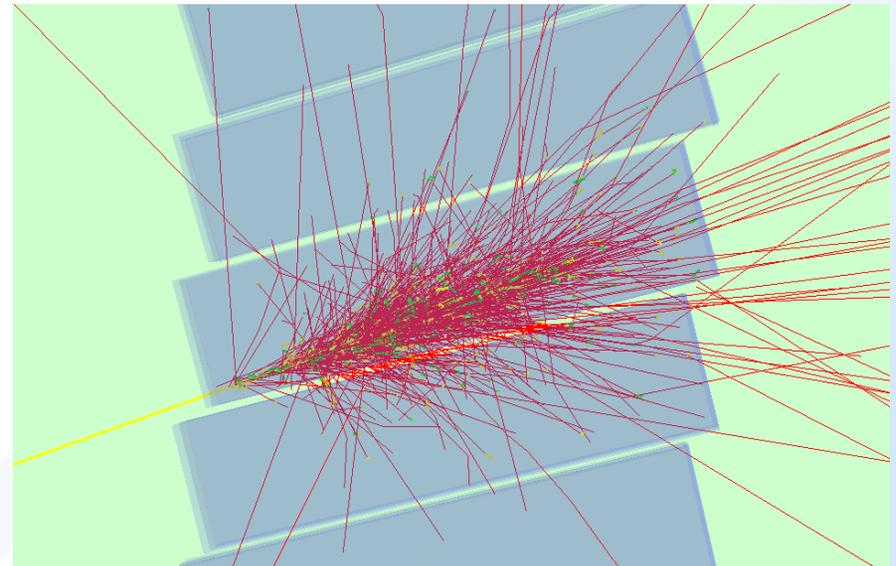
-> more work on improving light collection uniformity is needed

BACKWARD EM CALORIMETER (BEMC)



10 GeV/c electron hitting one of the four BEMC quadrants

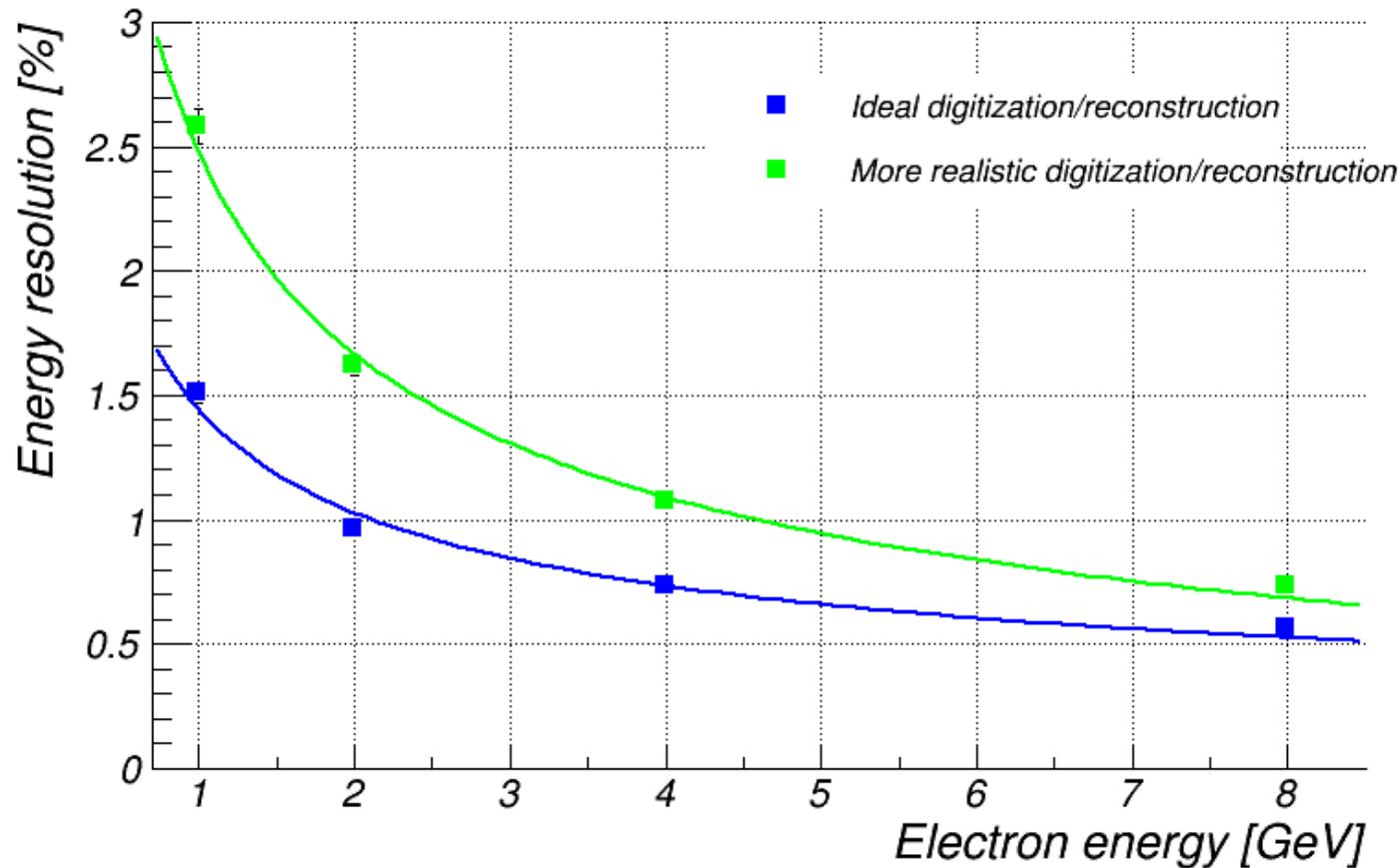
- PWO-II, layout like CMS & PANDA
- -2500mm from the IP
- both projective and non-projective geometry implemented
- digitization based on parameters from PANDA R&D (no cooling)



Same event (details of shower development)

BEMC ENERGY RESOLUTION

non-projective geometry; $\eta = 2.0$

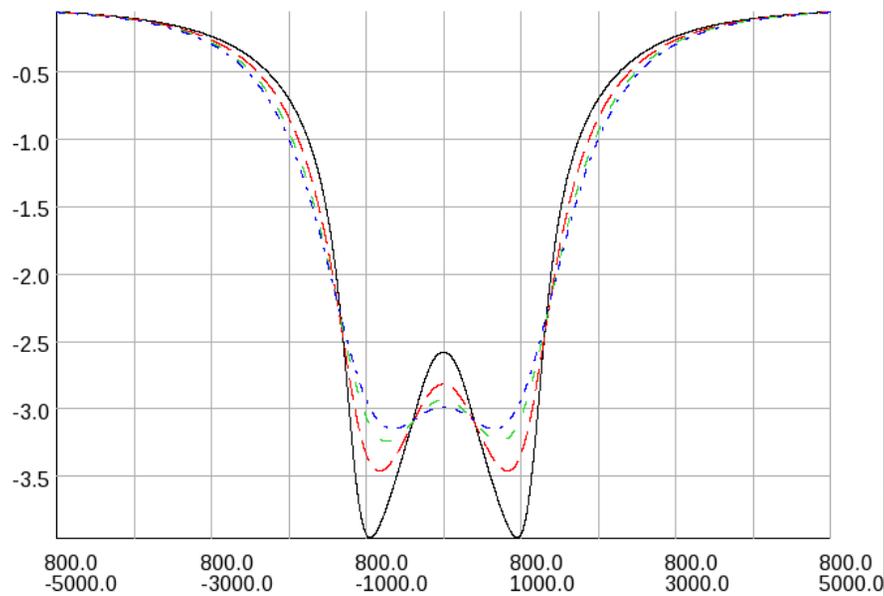
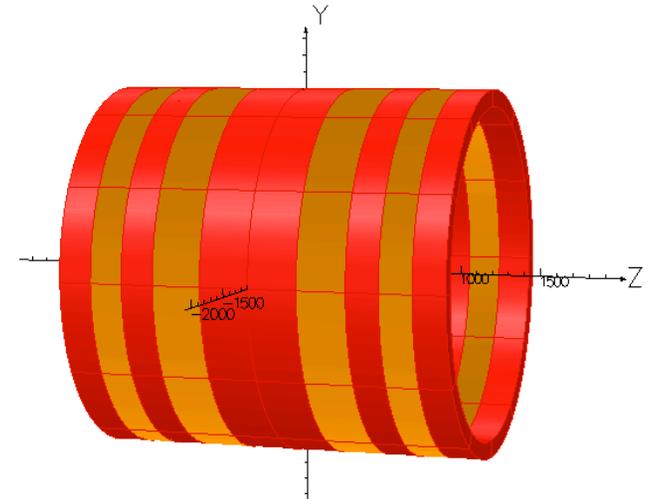


- "Realistic" digitization stands for: light yield 17pe/MeV; APD gain 50, ENF 2.0, ENC 4.2k; 10 MeV single cell threshold;

Magnetic fields

EIC SOLENOID MODELING

- Of course, constant field option available
- OPERA 2D/3D output adapted

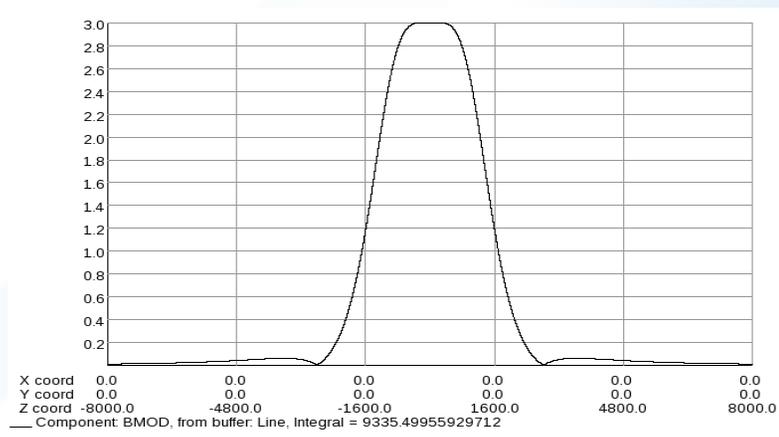
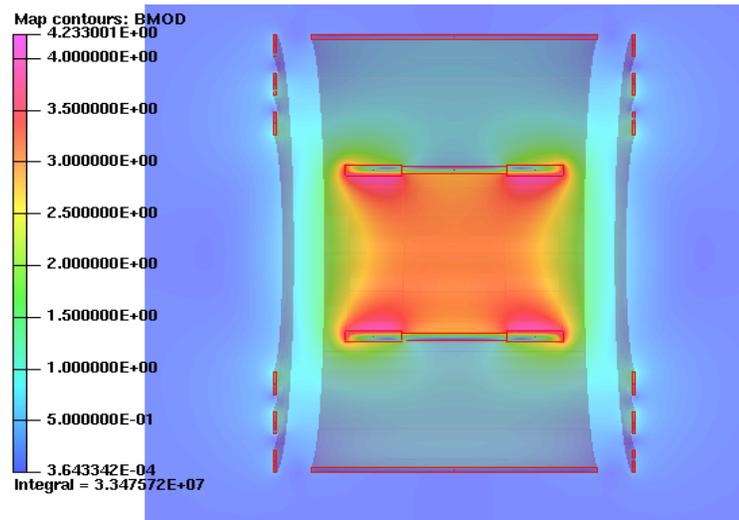
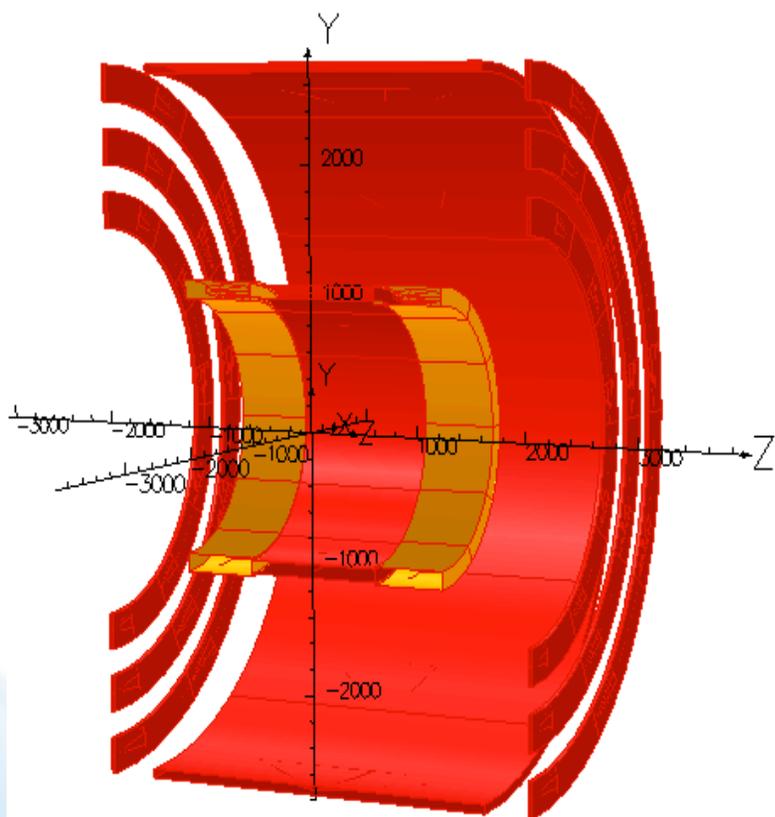


Presently used design: MRS-B1

Total Length : 2.4 m
Inner Radius : 1.0 m
Outer Radius : 1.1 m
Central B field: 3.0 T

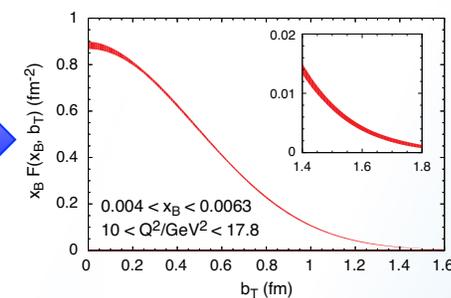
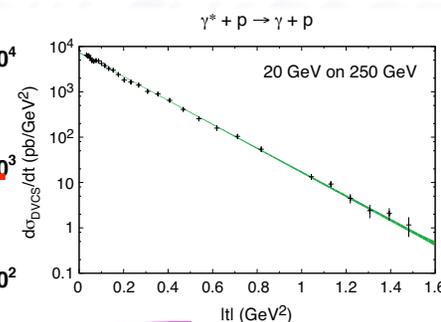
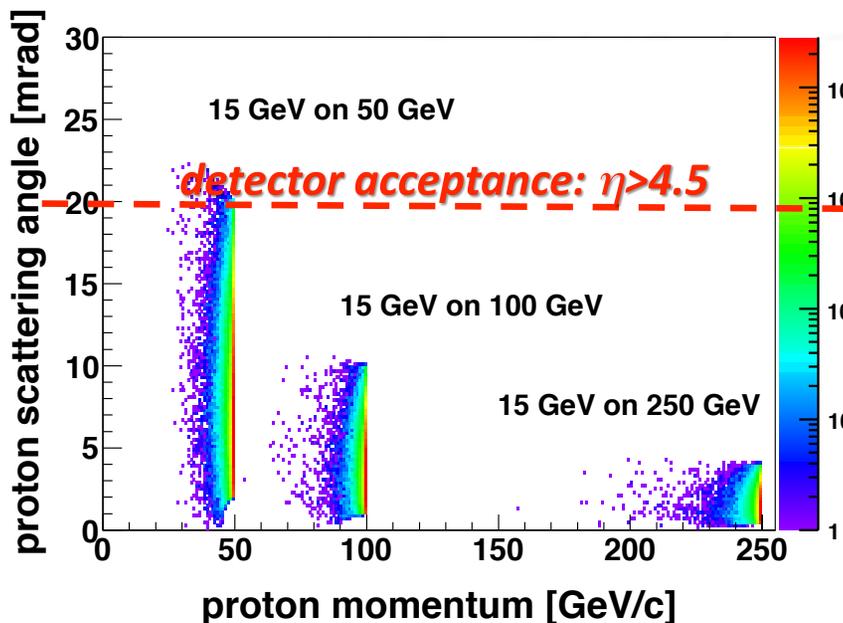
EIC SOLENOID MODELING

Other options investigated, like 4-th concept solenoid design



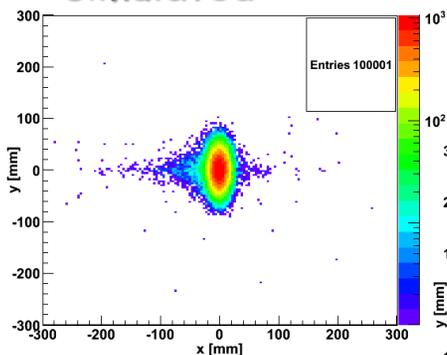
IR design

PROTONS FROM EXCLUSIVE REACTIONS

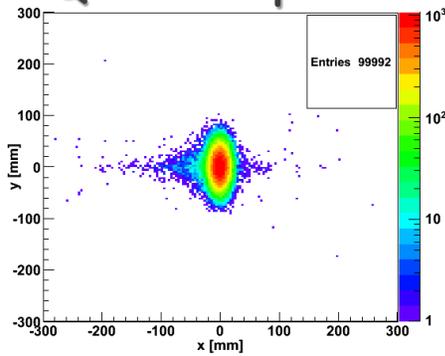


- t ($\sim p_t^2$) reach influences b_T uncertainty
 $t_{\min} \sim 0.175 \text{ GeV}^2 \rightarrow 300 \text{ GeV}^2 \delta f/f > 50\%$
- beam cooling critical to achieve high acceptance at low t (p_t)

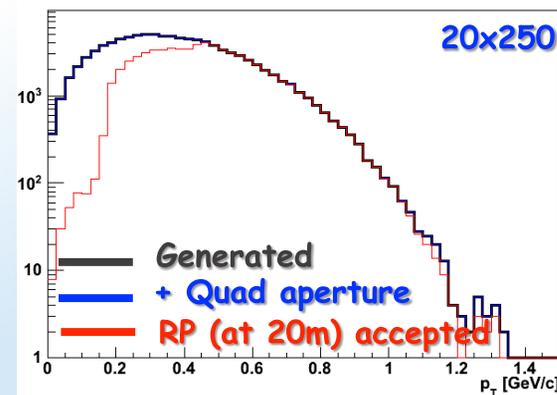
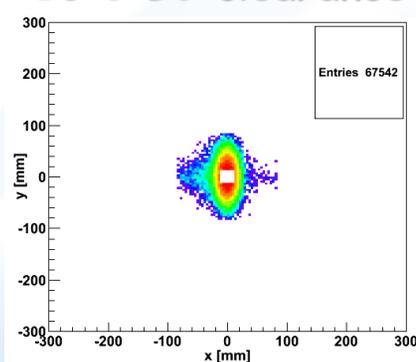
simulated



simulated + Quad-acceptance



simulated + Quad-acceptance + 10σ BC clearance

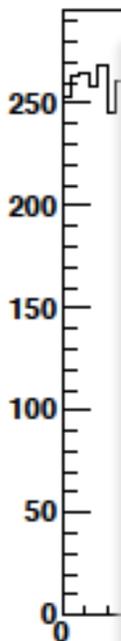


KINEMATICS OF BREAKUP NEUTRONS

Results from GEMINI++ for 50 GeV Au

theta distribution of neutrons at $E^* = 10$ MeV

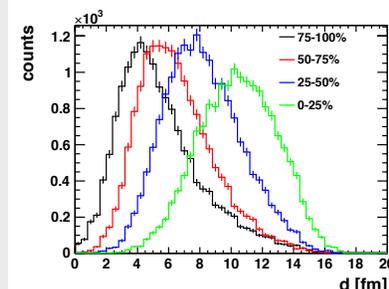
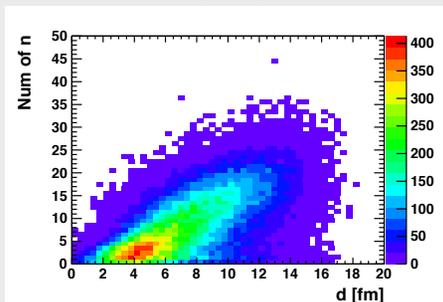
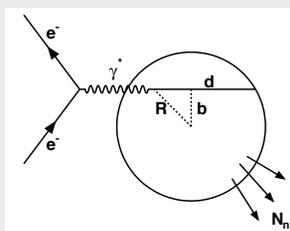
histoTheta10
Entries 9143



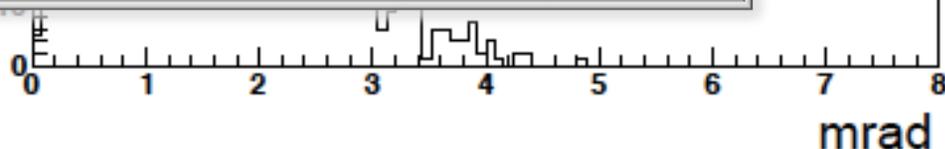
Important:

- For coherent VM-production rejection power of incoherent needed up to 10^4
 → ZDC detection efficiency is critical

Can we reconstruct the eA collision geometry:



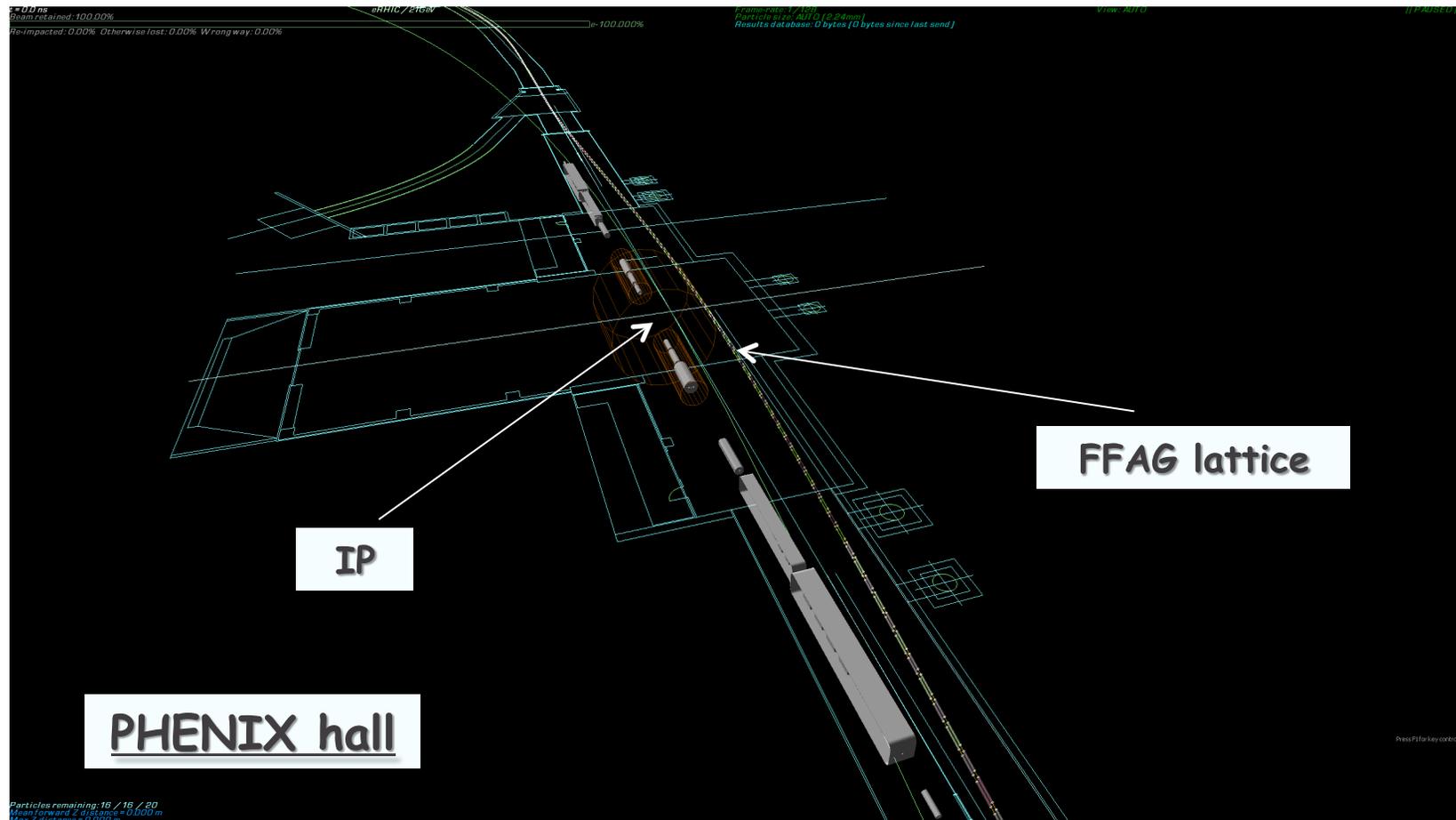
histoTheta500
Entries 2098
Mean 1.445
RMS 0.8048



↔ **+/- 5mrad acceptance seems sufficient**

IR DESIGN: FFAG BYPASS

by Stephen Brooks



-> space constraints in experimental area are rather tough!